Appendix F1 – Assessment of Controls (Watershed Restoration Assessment)

WHEEL CREEK
WATER CHEMISTRY MONITORING
YEAR 10 REPORT

Prepared for:

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1.0 INTRODUCTION

Harford County conducts monitoring in the Wheel Creek watershed to evaluate the benefits of various improvement projects, including stormwater pond retrofits and stream restorations. Wheel Creek has been identified as the County's priority watershed to satisfy National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit-required monitoring.

Wheel Creek watershed drains 435 acres consisting of high density residential and commercial land uses in the headwaters, and medium and low density residential and forest land uses in the remainder. The streams in the watershed have been altered by changes in hydrology associated with recent urbanization and historical agricultural land use. Imperviousness has increased to 27% in the past three decades of development (Harford County DPW 2008). In total, eight individual construction projects have been completed in tributaries and stormwater facilities in the watershed during 2012 to 2017 in an effort to improve instream chemical, biological, and physical conditions.

Monitoring to assess the effectiveness of the restoration effort in the Wheel Creek watershed to comply with the requirement of the MS4 permit has been ongoing since 2009. Harford County contracted with Versar, Inc., to conduct water chemistry and continuous flow monitoring. Previously, monitoring was performed in conjunction with requirements associated with the Chesapeake and Atlantic Coastal Bays 2010 Trust Fund stream restoration initiative, which included funding for the restoration projects and continuous flow, biological, and physical monitoring performed by Maryland Department of Natural Resources (DNR). Monitoring requirements for the Trust Fund stream restoration initiative have since been satisfied. Baseflow water chemistry monitoring, previously undertaken by County staff, has been conducted by Versar beginning in 2018. Continuous flow monitoring near all three of the water chemistry monitoring stations has been conducted by Versar from June 2016 to the present. Biological and physical monitoring have been conducted by KCI Technologies beginning this reporting period. Geomorphological assessments have been conducted annually since 2010, first by the County and subsequently by Versar. United States Geological Survey (USGS) operates a stream flow gauging station near the mouth of Wheel Creek (USGS Station 0158175320) and a stage level gauging station and tipping bucket rain gauge in Atkisson Reservoir (USGS Station 01581753).

This report documents the water chemistry monitoring activities undertaken by Harford County, Versar, and USGS, and summarizes the data obtained from July 1, 2019 to June 30, 2020. The activities included capturing eight wet weather events, monthly baseflow monitoring, and continuous flow rate monitoring in the Wheel Creek watershed. An assessment of long-term pollutant concentration trends and reduction by the restoration projects is also presented.

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2.0 STUDY AREA AND STUDY DESIGN

Wheel Creek forms a portion of the Atkisson Reservoir Watershed and resides within the Bush River Basin. It consists of approximately 435 acres of watershed, 2.2 linear stream miles, and five stormwater management facilities. Four stream reaches were targeted for restoration and four stormwater facility retrofits were planned in the drainage area (Harford County DPW 2008). Restoration and retrofit activities began in 2012 and continued through April 2017 (Table 2-1). Pre-construction and post-construction data will be used to assess performance of a portion of the stream restoration and stormwater BMP retrofit projects. The current monitoring period represents the third full year of post-restoration data collection and analyses.

Table 2-1. Timeline of restoration and retrofit projects in Wheel Creek watershed (M. Dobson pers. comm.)

Construction Projects	Start Date	Completion Date
Gardens of Bel Air (Pond A)	September 8, 2012	December 20, 2012
Calverts Walk (UMS-1)	January 14, 2013	April 4, 2013
Festival of Bel Air (Pond C)	May 12, 2015	August 7, 2015
Country Walk 1A (Pond D)	September 21, 2015	December 11, 2015
MMS-5, MB-4, MB-1	December 7, 2015	February 26, 2016
Water Quality Facilities (4)	December 7, 2015	March 18, 2016
Lower Wheel Creek	September 19, 2016	March 2017
Country Walk 1B (Pond E)	December 2016	April 2017

The water chemistry monitoring study design employs before and after conditions assessments corresponding to comparisons of pre- and post-restoration and retrofit phases. The initiation, termination, and duration of the phases vary by station and the schedule of restoration construction.

Three long-term automated water chemistry sampling and flow logging stations were established at Stations WC002, WC003, and WC004 (Figure 2-1). Station WC004 is located on the middle branch, immediately downstream of the stormwater retrofit at Festival Shopping Center (Point C). Stations WC003 and WC004 bracket completed stormwater retrofits at Pond D and Pond E along the middle branch. Station WC002 is located on the mainstem and water chemistry data collected there will provide an overall assessment of the benefits of retrofit and restoration projects in upstream tributaries (Figure 2-2). Baseflow monitoring took place at three stations along the Wheel Creek main stem and tributaries (WC002, WC003, and WC004).

Figure 2-1. Wheel Creek Watershed long-term water chemistry monitoring stations

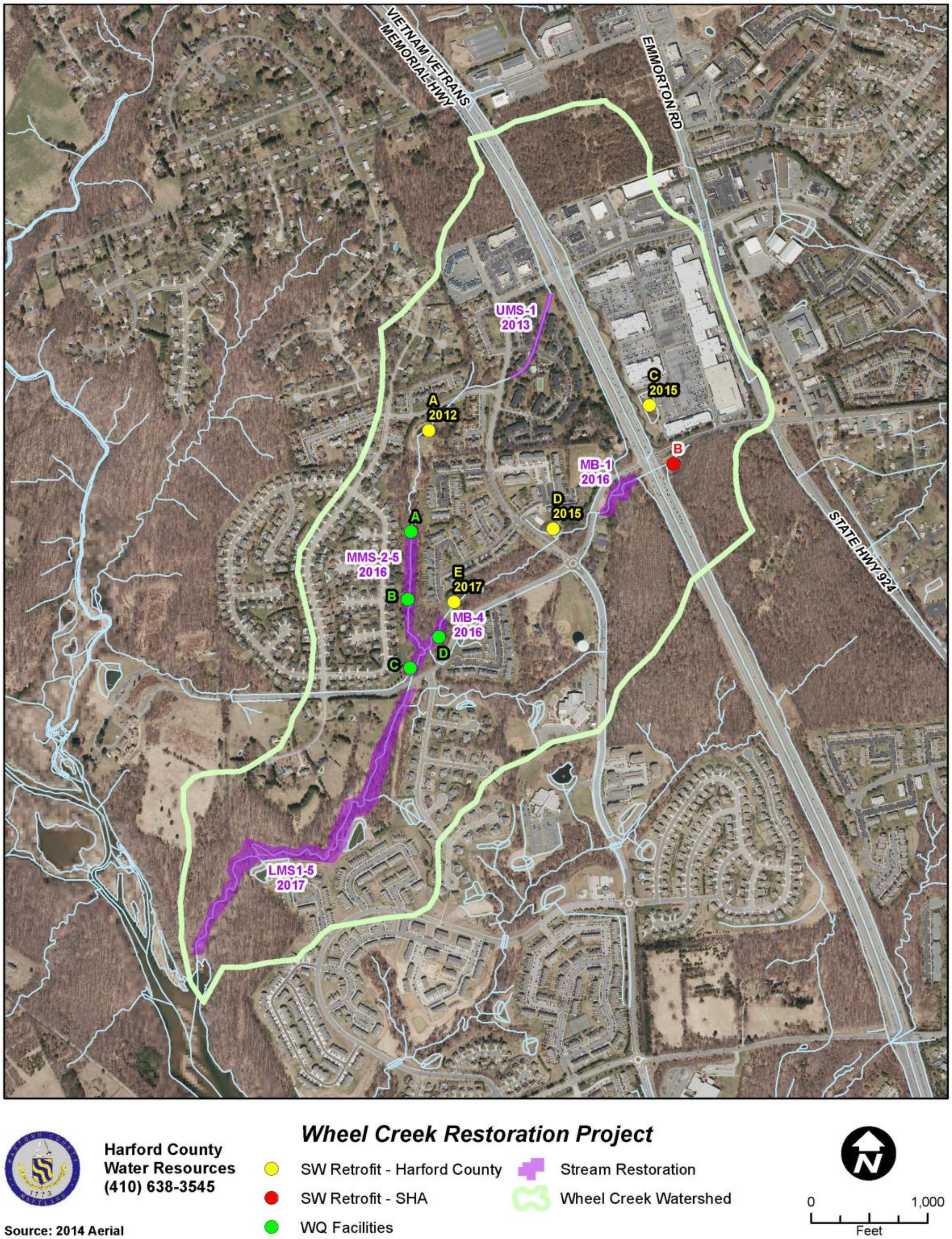

Figure 2-2. Stream restoration and stormwater retrofit sites in Wheel Creek watershed.

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3.0 METHODS AND MATERIALS

3.1 STORMFLOW MONITORING

Fixed, automated stormflow monitoring and long-term flow logging stations were situated at the following locations:

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

Stormflow samples were collected by Versar staff using American Sigma 900Max samplers at Stations WC002, WC003, and WC004 working in conjunction with ISCO 4230 bubbler flow meters. Automated sampling equipment was installed in September 2010 at Station WC002 and Station WC003 and mid-October 2010 at Station WC004. During storms, bubbler flow meter tubing and carriers were secured at the downstream end of culverts at Station WC002 and Station WC003 while the bubbler tube at Station WC004 was secured instream. Automated samplers contained 24, one-liter polypropylene bottles and were programmed to start at a specific time (based on the storm forecast) by field staff to sample the rising, peak, and falling limbs of the storm on a time-paced basis. Separate composite samples were created on a discharge volume-proportional basis to represent the rising, peak, and falling limbs of the stream hydrograph.

Eight events were monitored between July 1, 2019 and June 30, 2020 (Table 3-1). Event rainfall duration was calculated from the first to the last measurable amounts of rain that triggered the tipping mechanism within the rain gauge. Antecedent dry time was calculated by determining the time interval between the initiation of rainfall for the monitored event and the cessation of rainfall for the prior event. Qualifying storm events required a minimum of 24 hours where there had been less than 0.03 inches total accumulated rainfall.

Flow rate during monitored storm events was determined using Manning's equations specific to each outfall pipe at Stations WC002 and WC003 and by rating curve at Station WC004. The rating curve at Station WC004 was prepared using directly-measured velocities, over a range of stages, along a stream channel cross-section (Appendix B). Versar field staff measured velocity and channel depth using a Marsh-McBirney Flowmate 2000 flowmeter, with sensor attached to a graduated wading rod (Jones and Hage 2011). Automated storm sampling procedures are described in fuller detail in the project's Quality Assurance and Quality Control Document (Jones and Hage 2011). The duration of a storm event was recorded as the time of elevated flow (Appendix A). Stations WC003 and WC004 were found to have flow levels above baseflow longer than Station WC002 for several monitored storm events. These prolonged periods of elevated flow for these stations were possibly due to the stormwater ponds upstream of them detaining and releasing water over an extended period of time, where the continued discharge from these stormwater ponds contributed to flows above baseflow in the smaller upstream station systems where channels are narrower, and flows elevate easier.

Stream water samples were tested for the analytes listed in Table 3-2. Since May 2013, samples were tested for an expanded suite of analytes that included turbidity and chloride. Analytes with multiple detection limits are presented as a range in Table 3-2.

Table 3-1. Statistics for monitored storms, July 2019 – June 2020

Date	Rainfall Total (in.)	Rainfall Duration (hr.)	Antecedent Dry Time (hr.)
7-Oct-19	0.39	7.2	91.7
9-Oct-19	0.18	1.3	37.3
22-Oct-19	0.72	4.2	42.4
9-Dec-19	0.87	18.3	106.8
5-Feb-20	0.17	36.6	23.1
12-Feb-20	0.24	15.6	31.1
12-Apr-20	3.65	17.4	81.0
20-June-20	1.57	5.0	118.8

Rainfall recorded by primary onsite rain gauge at Station WC002

Table 3-2. Parameters, methods, detection limits, and water quality criteria for Wheel Creek monitoring

Parameter	Analytical Method	Reporting Limit (mg/L)	Method Detection Limit (mg/L)	MD Freshwater Criteria[a]		EPA Recommended Ambient Water Quality Criteria[b] (mg/L)
				Acute (μg/l)	Chronic (μg/l)	
BOD-5	SM 5210 B	0.9-1	0.9-1			
Nitrate + Nitrite	SM 4500 NO3F	0.2	0.02			0.69 (Total N)[c]
Total Kjeldahl Nitrogen	SM 4500 NorgD	0.5	0.1			
Orthophosphate	SM 4500 PE	0.05-0.07	0.009-0.02			
Total Suspended Solids	SM 2540D	1-3	1-3			
Copper	EPA 200.8	0.002-0.004	0.0002-0.0005	13	9	
Lead	EPA 200.8	0.001-0.002	0.00006-.0001	65	2.5	
Zinc	EPA 200.8	0.01-0.02	0.002-0.005	120	120	
Chloride[d]	EPA 300.0	5-50	5-50			860 (acute) 230 (chronic)
Ammonia	SM 4500 NH3H	0.3	0.05			
Total Phosphorus	SM 4500 PB&E	0.005-0.01	0.05			0.03656
Hardness	SM 2340C	10-20	10-20			
Turbidity	HACH 10258	0.01	0.01			
Total Petroleum Hydrocarbons	EPA 1664A	5	5			
E. coli (reported as MPN/100 ml)	SM 9223B	1	1			

(a) Values from COMAR 26.08.02.03-2 (undated).
(b) U.S. EPA 2000. Recommended criteria are derived from the 25th percentile of concentrations in all streams in the ecoregion.
(c) Total nitrogen concentration is the sum of total Kjeldahl nitrogen and combined nitrate plus nitrite.
(d) U.S. EPA 1988. Ambient Water Quality Criteria for Chloride.

Storm event mean concentrations (EMCs) were calculated individually for each storm by obtaining the concentration of each pollutant, weighted according to limb discharge volume. Limb discharges were determined by plotting the portion of the storm hydrograph represented by the composite sample and integrating under the curve using Flowlink software. For TPH and *E. coli*, which were collected by grab during irregular occasions during stormflow, a simple average concentration without flow weighting was calculated ("greater than" *E. coli* results were set to the numerical result).

Estimated pollutant loading values for each storm were determined by multiplying the storm EMCs by the total storm discharge in cubic feet. Total storm discharge was determined by plotting the storm hydrograph and integrating under the curve using Flowlink software.

3.2 BASEFLOW MONITORING

Baseflow monitoring was completed monthly by Versar staff. Grab samples were collected at the locations listed below.

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

3.3 LONG-TERM FLOW RATE LOGGING

Long-term flow rate logging was conducted at Stations WC002, WC003, and WC004 described above. Maryland DNR installed Solinst flow loggers in 2012 and maintained them through June 2016, at which point Versar assumed responsibility for monitoring and maintenance. Versar conducted monthly site inspections, logger downloads, and baseflow discharge measurements between July 2019 and June 2020. Storm discharge measurements were also collected whenever possible to verify the rating curve at each station.

During the winter months, the Solinst flow loggers were removed from service to prevent damage to the sensors due to icing. During these periods, ISCO 4230 bubbler flow meters were installed to capture level data while the Solinst loggers were offline.

Complete flow series for each station were compiled from the Solinst and ISCO logger data. Staff performed quality control on the level time series to remove any anomalous data (e.g., resulting from manipulation during Solinst data offloads). Levels were corrected to reflect observed staff gauge readings, and linear drift corrections were applied to the time series at each station to compensate for logger drift. A rating curve was established at each of the three logging stations to convert each logger's level data to flow rate (Appendix B).

3.4 RAINFALL LOGGING

Rainfall was recorded by an Onset HOBO electronic, tipping-bucket rain gauge situated in an open area near Station WC002. The gauge was downloaded and maintained by Versar field staff and is the primary gauge used for storm event rainfall totals. Daily rainfall recorded by the gauge is presented in Appendix C. Rainfall records from USGS' Atkisson Reservoir gauge (0.8 miles away to the SW), the secondary rainfall recorder, were used to supplement the onsite data in cases where onsite gauge data were unavailable due to power interruptions or mechanical failures. When the onsite rain gauge experienced a malfunction, a local Weather Underground station (www.wunderground.com; Bel Air South Station) was used for storm event rainfall totals since it is closer to the monitoring stations than the USGS gauge; the USGS rain gauge represents the official totals used for comparison over the entire duration of the year.

3.5 DETERMINATION OF STORM EVENT POLLUTANT LOADS

Pollutant loads were determined by multiplying the pollutant event mean concentration (a stream flow volume-weighted mean of analytical results from laboratory analysis) by the total storm discharge at the point of sample collection. Stream discharge volume for a specific time interval (for a specific limb or the total event) is determined by integrating under the flow rate hydrograph over the time period of interest. The pollutant event mean concentration (EMC) for a given storm is determined by:

$$\mathrm{EMC} = \frac{\sum_{i=1}^{3} C_i V_i}{\sum_{i=1}^{3} V_i}$$

Where:

EMC = Event Mean Concentration of specific pollutant

i = Numerical representation of storm limb (1=rising, 2=peak, 3=falling)

C_i = Pollutant concentration at limb i

V_i = Corresponding discharge represented by composite sample collected for limb i.

The average pollutant EMC for the monitoring year is an arithmetic mean of individual storm EMCs.

Pollutant load for a given storm is calculated by:

$$L = (k_1 / k_2) \text{ x } (\mathrm{EMC} \text{ x } V_T)$$

Where:

L = estimated load in pounds
k_1 = conversion factor 28.317 liters per cubic foot
k_2 = conversion factor of 453,592.4 milligrams per pound
V_T = estimated total storm runoff in stream in ft^3

The average pollutant load for the monitoring year is an arithmetic mean of individual storm loads.

3.6 DETERMINATION OF AVERAGE ANNUAL AND SEASONAL EMC AND TOTAL ANNUAL AND SEASONAL LOAD

Average annual storm EMCs for each pollutant at each station were determined by obtaining the arithmetic mean of individual storm EMC data for a given year. Average annual baseflow Mean Concentrations (MCs) were developed by calculating the arithmetic mean of concentration data. Average seasonal EMCs and MCs were obtained by using the same method, except on a seasonal basis. Below-reportable detection limit results were set to zero when determining average EMCs and determining baseflow MCs.

Total annual load was determined by (a) multiplying all stormflow volume in a given year at a given station by the corresponding average annual EMC for each pollutant, (b) multiplying all baseflow volume in the same year by the corresponding average annual MC, and (c) summing the result.

3.7 SUSPENDED SEDIMENT TRANSPORT MONITORING

Suspended sediment transport was monitored at all three Wheel Creek storm monitoring stations, WC002, WC003, and WC004 (Figure 2-1). Sediment samples were collected in conjunction with wet weather samples from July 2019 through June 2020. Suspended sediment was monitored during eight wet weather sampling events using a modified siphon sampler (Diehl 2008) outfitted with a HOBO® U20 depth logger for continuous stage recording. The modified siphon sampler was developed by USGS to sample shallow water at closely spaced vertical intervals, enabling samples to be collected passively at multiple stages of the rising limb of the hydrograph. Each sampler included six 1000-mL sample containers oriented horizontally with an intake tube and an air vent, which allowed sample collection at up to six two-inch incremental stages. Samples collected were analyzed individually for suspended sediments following a standard method for total suspended solids (SM2540D; APHA 1999), with filtration of the full 1000-mL sample.

Since the sampler devices could not be deployed in the same location as the gauge recorders without causing interference, discharge corresponding to each sample was determined using depth data obtained from the HOBO® loggers. The loggers were set to record pressure and temperature data at 5-minute intervals for the full duration of their deployment. The logger data were then post-processed using HOBOware Pro 2.7.3 software, to correct for changes in barometric pressure. The resulting data were used to determine the approximate time that each sample bottle was filled, and the corresponding discharge from the time of sample collection was obtained from the storm event flow rate graphs for each station. The relationship between discharge and suspended sediment concentration was then plotted to create a sediment-transport curve (Glysson 1987) for each station.

3.8 STATISTICAL TEST FOR TREND

A Kendall's Tau-b statistical test (Kendall 1948) was performed on the compiled baseflow concentration and individual storm EMC data at the monitoring stations. This test is a non-parametric test that compares the ranks of parameter concentrations to the ranked collection dates. The test was used to determine whether a significant upward or downward trend in concentration occurred over time.

3.9 COMPARISON OF PRE- TO POST-RESTORATION DATA

The assessment of the effectiveness of restoration projects in Wheel Creek relies upon comparisons of pre-restoration conditions to post-restoration conditions. Because the implementation of restoration projects in the watershed was staggered, the effectiveness of groups of the projects was determined strategically using the location of the applicable monitoring station and construction timelines. The time periods for the pre-restoration and post-restoration conditions were appropriately defined at each station, so that the during-construction phases were eliminated from the comparisons. Note the following:

- Pre-restoration and post-restoration conditions evaluated using data from Station WC004 were governed only by the construction of Pond C at Festival of Bel Air,
- Pre-restoration phase for data collected at Station WC002 was governed by the earliest construction of projects on the mainstem (i.e., Pond A in September 2012),
- Pre-restoration phase for data collected at Station WC003 was governed by the start of construction at Pond C in May 2015 (same as at Station WC004) but was set to the same timeframe as Station WC002 for consistency, and
- Post-restoration phase at both Station WC002 and Station WC003 was set to the conclusion of construction of Pond E at Country Walk 1B in April 2017 since the effort was upstream of both stations.

The relationship between restoration construction schedule, which monitoring station data are used in efficiency evaluations, and the type of evaluations are provided in Table 3-3.

Comparisons were conducted in two ways: a) total annual load for fiscal years 2017-2019 (post-restoration) to 2010-2011 (pre-restoration); and b) post-restoration storm EMCs and baseflow MCs to pre-restoration storm EMCs and baseflow MCs.

3.9.1 Comparison of Ratios Between Stations WC002 and WC003

Because only one monitoring station is located on the mainstem, the assessment of the effectiveness of restoration projects in improving water quality in the mainstem, as well as projects on the middle branch located between Station WC002 and Station WC003 (e.g., MB-4 and one water quality facility), was isolated and performed indirectly by comparing ratios of pollutant loads and concentrations between the stations during the pre-restoration and post-restoration phases. The ratio (or relationship) of pollutant levels between the two stations during the pre-restoration period was taken as a baseline; a lowering of the ratio during the post-restoration period would indicate pollutant reduction between the stations.

The ratio of total load between the downstream station and the upstream station was calculated for the following pollutants: total nitrogen, total phosphorus, total suspended solids (TSS), ammonia, BOD, copper, lead, and zinc.

For this method, total loads were calculated using data from the pre-restoration period (2010-2011) and post-restoration period (FY 2017-2020) and then compared to one another. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (L_3/L_2)) * 100$$

Where:

L_3 = Load at Station WC003 (upstream)
L_2 = Load at Station WC002 (downstream)

To determine restoration effectiveness in terms of storm EMC and baseflow MC, the ratio between the average EMC or MC at the downstream Station WC002 and the upstream Station WC003 was calculated for the pre-restoration time period and the post-restoration time period. The ratios of average concentrations between the downstream station and the upstream station, during both periods, were compared for each analyte. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (C_3/C_2)) * 100$$

Where:

C_3 = Concentration at Station WC003 (upstream)
C_2 = Concentration at Station WC002 (downstream)

A paired Student's t test was used to determine significance of the difference in EMC or MC between the stations.

3.9.2 Comparison of Pre- and Post-Restoration Conditions at all Stations

Calculations of absolute pollutant removal efficiencies were used to characterize the aggregated effectiveness of restoration projects located within each station's subwatershed. Both storm EMC and baseflow MC data accumulated during the pre-restoration and post-restoration phases at each station, defined above, were compared. The efficiencies were calculated using the same percentage equation defined in Section 1.2.1. A Student's t test was used to determine significance.

Table 3-3. Restoration construction schedule, applicable monitoring stations, and recommended efficiency evaluation methods

<table>
<tr><th rowspan="2">Construction Projects</th><th rowspan="2">Reach</th><th rowspan="2">Start Date</th><th rowspan="2">Completion Date</th><th colspan="2">No. Storms</th><th colspan="2">No. Baseflows</th><th rowspan="2">Efficiency Evaluation</th></tr>
<tr><th>Pre-restoration</th><th>Post-restoration</th><th>Pre-restoration</th><th>Post-restoration</th></tr>
<tr><td>Gardens of Bel Air (Pond A)</td><td>Mainstem</td><td>September 8, 2012</td><td>December 20, 2012</td><td rowspan="4">17 (WC002)
18 (WC003)</td><td rowspan="4">33 (WC002)
32 (WC003)</td><td rowspan="4">33 (WC002)
32 (WC003)</td><td rowspan="4">50 (WC002)
50 (WC003)</td><td rowspan="4">Compare differences between WC002 & WC003 during pre- and post-conditions</td></tr>
<tr><td>Calverts Walk (UMS-1)</td><td>Mainstem</td><td>January 14, 2013</td><td>April 4, 2013</td></tr>
<tr><td>MMS-5, MB-4</td><td>Mainstem, Middle Branch</td><td>December 7, 2015</td><td>February 26, 2016</td></tr>
<tr><td>Water Quality Facilities (4)</td><td>Mainstem (3), Middle Branch (1)</td><td>December 7, 2015</td><td>March 18, 2016</td></tr>
<tr><td>Festival of Bel Air (Pond C)</td><td>Middle Branch</td><td>May 12, 2015</td><td>August 7, 2015</td><td>42</td><td>42</td><td>52</td><td>57</td><td>WC004 before & after</td></tr>
<tr><td>Country Walk 1A (Pond D)</td><td>Middle Branch</td><td>September 21, 2015</td><td>December 11, 2015</td><td rowspan="3">17 (WC002)
18 (WC003)</td><td rowspan="3">26 (WC002)
27 (WC003)</td><td rowspan="3">33 (WC002)
32 (WC003)</td><td rowspan="3">36 (WC002)
36 (WC003)</td><td rowspan="3">WC002 before & after; WC003 before & after</td></tr>
<tr><td>MB-1</td><td>Middle Branch</td><td>December 7, 2015</td><td>February 26, 2016</td></tr>
<tr><td>Country Walk 1B (Pond E)</td><td>Middle Branch</td><td>December 2016</td><td>April 2017</td></tr>
</table>

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4.0 RESULTS AND DISCUSSION

Results of stormflow and baseflow sampling performed from July 1, 2019 through June 30, 2020 are presented and discussed in this section. The individual sample analytical data are compiled into tables while annual average concentrations and loadings are presented in tabular and graphical form.

4.1 STORMFLOW CONCENTRATION RESULTS

Analytical results for storm samples collected at each of the three stations are presented in Table 4-1. Total nitrogen results were greater than the EPA recommended reference value of 0.69 mg/L (U.S. EPA 2000) in 100% of the samples in this monitoring period. Of the samples in which total phosphorus was detected, 52.8% of the results were greater than the EPA recommended reference value of 0.03656 mg/L. Orthophosphate was detected in 23.6% of stormflow samples collected. Ammonia results were above the detection limit in 61.1% of stormflow samples collected at all stations during the year. Ammonia concentrations were highest during the April and June storm events. BOD was detected in 79.2% of samples, with the highest concentrations at all three stations during the April 14, 2020 storm event.

Zinc was detected in 94.4% of storm samples collected between July 1, 2019 and June 30, 2020. No zinc concentration was greater than MDE's acute criterion for surface water in samples collected during this reporting period (Table 3-2).[1] Zinc concentrations were highest during the October 8, 2019 storm event. Lead concentrations were above the detection limit in 26.4% of the samples, none of which were above the MDE acute criterion. Copper concentrations were above the detection limit in 90.3% of samples; however, only 5.6% were greater than the MDE acute criterion for surface water.

E. coli concentrations were equal to or greater than the maximum reportable result (2,420 MPN/100ml) in 19.0% of stormflow grab samples. *E. coli* concentrations were generally highest at Station WC002, although two of the four concentrations that were equal to or greater than the maximum reportable result were reported at Station WC004. TPH was not detected in any of the 21 stormflow grab samples collected at the monitoring stations. Hardness was generally the lowest at Station WC004. Turbidity was generally highest at Station WC003, probably due to the additive effects of suspended matter transported from the stormwater collection pond just upstream of this station. TSS was above the detection limit in 88.9% of samples, with highest concentrations also at Station WC003. Chloride was reported in all but one of the storm runoff samples, but none of the reported results exceeded the acute criterion established by USEPA. Chloride concentrations were less than those seen in previous years, probably due to the milder winter and reduced flushing of deicing compound applied on road surfaces.

[1] The zinc, lead, and copper criteria are based on the dissolved form, while the laboratory analytical results are for total metal concentration. Comparisons to surface water criteria are for discussion purposes only and do not imply violations of surface water standards.

4.2 BASEFLOW CONCENTRATION RESULTS

Baseflow sample analytical results are presented in Table 4-2. Under baseflow conditions, concentration values for total phosphorus were above the detection limit in 47.2% of samples. Orthophosphate was not detected in any of the baseflow samples. Ammonia was detected in 55.6% of samples, mostly at Station WC002, and TSS was detected in 52.8% of baseflow samples. Total nitrogen was above the detection limit in all the baseflow samples and all concentration levels were greater than the EPA reference value (0.69 mg/L). Total nitrogen concentrations tended to be lowest at Station WC003.

Zinc was detected in all baseflow samples and generally at the highest concentrations at Station WC004. Lead and copper were detected in 36.1% and 61.1%, respectively, of baseflow samples. All concentrations of all metals were lower than MDE's applicable chronic surface water criteria.

BOD was detected in 25.0% of samples. Maximum BOD concentrations at all three stations were recorded for the January and April baseflow monitoring events. Baseflow concentrations of nitrate plus nitrite were generally higher at Station WC004 than at the other stations. Turbidity was generally lowest in baseflow samples taken from Station WC004 and highest in baseflow samples taken from Station WC003.

Chloride concentrations were elevated in July through October for all stations. Generally, chloride was highest at Station WC004 for a given baseflow sampling event and became gradually lower when progressing downstream to Station WC002. The maximum observed chloride concentrations for Station WC004 occurred during the October sampling event and for Stations WC002 and WC003 occurred during the September sampling event. The lowest chloride concentrations occurred during the December sampling event at Stations WC002 and WC003, and during the June sampling event at Station WC004.

Hardness, a characteristic of surface waters, was quantified in all baseflow samples. Concentrations greater than 120 mg/L are considered "Hard", while concentrations exceeding 180 mg/L are considered "Very Hard". All baseflow samples collected contained "Very Hard" water, and the highest hardness values were found at Station WC004.

E. coli bacteria concentrations were detected in all baseflow samples, when tested, at all stations, ranging in concentration from 8.5 to 1,990 MPN/100ml. The maximum concentrations during the monitoring period for Stations WC002 and WC003 occurred during the September sampling event, and the maximum concentration for Station WC004 occurred during the June sampling event. In general, *E. coli* concentrations were highest during the warmer months and lowest during the colder months.

TPH was not detected in any baseflow samples collected from the study area during the monitoring period.

Table 4-1. Stormflow water chemistry results, July 2019 – June 2020. All concentrations are in units of mg/L unless indicated.

Storm Date	Limb	Discharge (cf)	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophosphate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitrogen	Hardness	Chloride	Turbidity (NTU)
Station WC002																		
10/7/2019	Rising	7,487	<1	0.42	1.4	<0.05	1.4	0.13	51	5	<1	40	N.C.	N.C.	2.8	173	107	15
10/7/2019	Peak	36,941	2	<0.3	0.8	<0.05	1.7	0.21	64	9	2	51	N.C.	N.C.	2.5	112	77.1	20.3
10/7/2019	Falling	14,447	<1	<0.3	0.5	<0.05	0.9	0.06	9	4	<1	21	<5	>2420	1.4	72	52.2	6
10/9/2019	Rising	6,743	<1	0.45	1.1	<0.05	0.6	0.02	4	<2	<1	26	N.C.	N.C.	1.7	133	80.6	1.82
10/9/2019	Peak	27,599	3	0.08	0.5	<0.05	0.8	0.05	9	4	<1	29	N.C.	N.C.	1.3	59	58.2	4.94
10/9/2019	Falling	10,604	1	0.05	0.4	<0.05	0.6	0.02	2	<2	<1	<10	<5	488	1	80	58.7	3.56
10/22/2019	Rising	23,843	1	0.49	1.1	<0.05	0.5	0.009	<2	<2	<1	11	<5	548	1.6	131	93.4	1.22
10/22/2019	Peak	212,981	4	0.17	0.6	<0.05	1	0.1	28	7	1	32	N.C.	N.C.	1.6	92	56.4	9.29
10/22/2019	Falling	61,620	3	0.06	0.3	0.02	0.8	0.08	12	6	<1	30	N.C.	N.C.	1.1	44	14.4	10.4
12/9/2019	Rising	50,469	5	0.05	0.6	<0.05	0.6	0.12	18	5	<1	42	<5	35	1.2	80	57.3	9.98
12/9/2019	Peak	177,429	4	0.05	0.3	<0.05	0.6	0.1	13	6	<1	29	N.C.	N.C.	0.9	32	<25	11.3
12/9/2019	Falling	45,014	3	<0.3	0.6	<0.05	0.6	0.06	5	4	<1	29	N.C.	N.C.	1.2	50	29.6	7.4
2/5/2020	Rising	6,128	<1	0.3	1.3	<0.05	0.5	0.02	<2	<2	<1	16	N.C.	N.C.	1.8	122	151	5.03
2/5/2020	Peak	11,966	2	0.12	1.1	0.01	0.5	0.01	<2	2	<1	13	N.C.	N.C.	1.6	104	119	3.71
2/5/2020	Falling	10,361	1	0.06	1	<0.05	0.5	0.02	<2	2	<1	13	<5	108	1.5	102	128	2.97
2/12/2020	Rising	6,260	2	0.28	1.5	<0.05	0.4	0.02	9	2	<1	16	N.C.	N.C.	1.9	112	103	4.22
2/12/2020	Peak	13,685	2	0.06	1.1	<0.05	0.5	0.02	3	2	<1	11	N.C.	N.C.	1.6	93	85.2	4.36
2/12/2020	Falling	8,388	1	<0.3	1.1	<0.05	0.5	0.01	<2	2	<1	11	<5	43.2	1.6	98	80.3	2.95
4/12/2020	Rising	210,303	5	0.24	0.9	<0.05	1.2	0.16	9	9	2	43	N.C.	N.C.	2.1	93	65.7	4.66
4/12/2020	Peak	1,265,370	5	0.22	0.4	0.06	1.8	0.42	81	20	4	81	N.C.	N.C.	2.2	24	9.27	25.8
4/12/2020	Falling	330,946	3	0.15	0.3	0.06	1	0.17	30	10	2	26	<5	1200	1.3	23	12.3	29.8
6/20/2020	Rising	56859	4	0.17	1.1	0.02	1	0.13	26	5	1	24	N.C.	N.C.	2.1	125	79.7	8.54
6/20/2020	Peak	383228	3	0.19	0.4	0.02	1	0.13	20	8	<2	28	N.C.	N.C.	1.4	44	20.3	8.82
6/20/2020	Falling	53879	4	0.15	0.5	0.02	0.8	0.07	6	6	<1	16	N.C.	N.C.	1.3	36	17.1	4.6

N.C. = Sample Not Collected

Table 4-1. (Continued)

Storm Date	Limb	Discharge (cf)	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophosphate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitrogen	Hardness	Chloride	Turbidity (NTU)
Station WC003																		
10/7/2019	Rising	1,872	<1	<0.3	0.8	<0.05	1.6	0.19	68	10	2	65	N.C.	N.C.	2.4	160	93	30.7
10/7/2019	Peak	5,501	<1	<0.3	0.5	<0.05	1	0.07	21	4	<1	20	N.C.	N.C.	1.5	100	62.6	11.5
10/7/2019	Falling	1,839	<1	<0.3	0.3	<0.05	0.8	<0.05	5	3	<1	17	<5	1050	1.1	97	76.6	4.88
10/9/2019	Rising	1,117	1	<0.3	0.4	<0.05	0.7	0.03	6	<2	<1	13	N.C.	N.C.	1.1	128	96.8	4.42
10/9/2019	Peak	3,609	<1	0.05	0.3	<0.05	0.7	0.02	4	2	<1	<10	N.C.	N.C.	1	91	70.3	3.86
10/9/2019	Falling	1,854	<1	<0.3	0.2	<0.05	0.6	0.009	<2	<2	<1	<10	<5	248	0.8	98	79.6	3.22
10/22/2019	Rising	2,779	3	<0.3	0.4	<0.05	1	0.09	34	10	1	99	<5	>2420	1.4	108	64.7	9.98
10/22/2019	Peak	24,046	3	<0.3	0.3	0.02	1	0.12	37	9	2	39	N.C.	N.C.	1.3	52	22.7	13.5
10/22/2019	Falling	7,142	2	<0.3	0.3	<0.05	0.8	0.05	9	5	<1	14	N.C.	N.C.	1.1	42	22.3	7.81
12/9/2019	Rising	2,491	4	0.13	0.3	<0.05	0.7	0.04	16	6	<1	37	<5	90.5	1	52	37.8	11.3
12/9/2019	Peak	8,249	3	<0.3	0.3	<0.05	0.5	0.07	8	5	<1	32	N.C.	N.C.	0.8	38	23.3	9.34
12/9/2019	Falling	1,968	2	0.1	0.3	<0.05	0.5	0.05	4	5	<1	26	N.C.	N.C.	0.8	46	31.6	6.87
2/5/2020	Rising	1,466	<1	<0.3	1.1	<0.05	0.5	0.009	4	2	<1	23	N.C.	N.C.	1.6	154	160	6.91
2/5/2020	Peak	5,033	1	<0.3	0.9	<0.05	0.5	0.02	2	2	<1	13	N.C.	N.C.	1.4	142	177	3.76
2/5/2020	Falling	5,599	<1	0.06	0.8	<0.05	0.5	0.01	2	2	<1	13	<5	137	1.3	128	171	3.22
2/12/2020	Rising	1,802	2	<0.3	0.9	<0.05	0.4	0.01	3	2	<1	11	N.C.	N.C.	1.3	112	110	5.2
2/12/2020	Peak	4,901	1	<0.3	0.7	<0.05	0.4	0.009	<2	<2	<1	12	N.C.	N.C.	1.1	88	90	3.51
2/12/2020	Falling	3,903	2	<0.3	0.7	<0.05	0.4	0.02	4	2	<1	15	<5	649	1.1	79	81.3	5.82
4/12/2020	Rising	48,237	3	0.12	0.6	<0.05	1.1	0.12	53	10	2	38	N.C.	N.C.	1.7	102	86.5	9.12
4/12/2020	Peak	359,885	4	0.11	0.3	0.02	1.1	0.18	69	15	2	41	N.C.	N.C.	1.4	25	11.5	18.9
4/12/2020	Falling	84,474	2	0.34	0.3	0.02	0.8	0.11	28	10	2	23	<5	488	1.1	24	12.4	20.3
6/20/2020	Rising	10318	2	0.23	0.7	0.01	2.3	0.4	251	18	6	62	N.C.	N.C.	3	164	113	18.4
6/20/2020	Peak	119620	3	0.21	0.3	0.01	1.2	0.13	46	11	<2	50	N.C.	N.C.	1.5	50	31.7	9.21
6/20/2020	Falling	16180	1	0.2	0.3	0.01	0.8	0.04	19	5	<1	15	N.C.	N.C.	1.1	42	25.8	4.13

N.C. = Sample Not Collected

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC004																		
10/7/2019	Rising	1,700	2	<0.3	0.8	<0.05	1.6	0.13	43	15	2	68	N.C.	N.C.	2.4	112	72.1	18.2
10/7/2019	Peak	4,263	<1	<0.3	0.4	<0.05	1.1	0.05	17	7	<1	35	N.C.	N.C.	1.5	48	29.1	7.51
10/7/2019	Falling	1,644	<1	<0.3	0.3	<0.05	0.9	<0.05	3	6	<1	31	<5	>2420	1.2	64	43.7	3.08
10/9/2019	Rising	539	1	<0.3	0.8	<0.05	0.8	0.009	8	3	<1	25	N.C.	N.C.	1.6	112	91.3	2.9
10/9/2019	Peak	2,501	2	<0.3	0.2	<0.05	0.7	0.02	3	3	<1	39	N.C.	N.C.	0.9	44	28.6	3.41
10/9/2019	Falling	838	<1	<0.3	0.3	<0.05	0.8	0.01	<2	2	<1	<10	<5	365	1.1	61	39.9	1.83
10/22/2019	Rising	5,151	3	0.06	0.7	<0.05	1	0.07	26	10	1	41	<5	>2420	1.7	68	63.7	8.81
10/22/2019	Peak	15,058	1	<0.3	0.2	<0.05	0.7	0.03	9	5	<1	19	N.C.	N.C.	0.9	20	9.18	4.86
10/22/2019	Falling	4,839	1	<0.3	0.2	<0.05	0.6	0.01	2	3	<1	14	N.C.	N.C.	0.8	26	14.9	2.88
12/9/2019	Rising	6,454	4	0.14	0.3	<0.05	0.9	0.07	13	8	1	52	<5	119	1.2	32	26.1	6.98
12/9/2019	Peak	18,355	2	0.14	0.2	<0.05	0.5	0.03	3	5	<1	44	N.C.	N.C.	0.7	17	9.43	4.89
12/9/2019	Falling	5,343	2	0.32	0.4	<0.05	0.5	0.02	4	4	<1	36	N.C.	N.C.	0.9	34	24.2	4.56
2/5/2020	Rising	1,769	3	0.06	0.9	<0.05	0.8	0.03	6	4	<1	35	N.C.	N.C.	1.7	116	231	4.07
2/5/2020	Peak	3,595	3	0.05	0.5	<0.05	0.8	0.03	3	5	<1	38	N.C.	N.C.	1.3	84	192	4.47
2/5/2020	Falling	3,300	2	0.06	0.6	<0.05	0.7	0.03	3	5	<1	37	<5	435	1.3	84	173	3.68
2/12/2020	Rising	1,670	2	<0.3	1.3	<0.05	0.5	0.03	5	3	<1	44	N.C.	N.C.	1.8	109	124	3.07
2/12/2020	Peak	3,453	2	0.06	0.5	0.02	0.6	0.06	137	9	9	57	N.C.	N.C.	1.1	54	58.9	14.4
2/12/2020	Falling	1,903	2	<0.3	0.8	<0.05	0.5	0.02	3	3	<1	29	<5	308	1.3	60	77.6	3.78
4/12/2020	Rising	15,886	3	0.22	0.6	<0.05	1.2	0.14	23	10	1	42	N.C.	N.C.	1.8	58	51.3	4.55
4/12/2020	Peak	72,653	2	0.12	0.2	0.02	0.8	0.07	17	8	1	24	N.C.	N.C.	1	13	5.66	11.5
4/12/2020	Falling	35,353	2	0.14	0.2	0.01	0.8	0.04	8	5	<1	21	<5	326	1	18	12	10.3
6/20/2020	Rising	3687	<1	0.06	2.1	<0.05	0.6	0.02	14	2	<1	21	N.C.	N.C.	2.7	210	177	1.42
6/20/2020	Peak	32005	2	0.42	0.2	0.01	0.7	0.05	11	6	<2	24	N.C.	N.C.	0.9	24	11.9	5.06
6/20/2020	Falling	11648	2	0.17	0.3	<0.05	0.7	0.03	3	4	<1	16	N.C.	N.C.	1	30	14.9	3.77

N.C. = Sample Not Collected

Table 4-2. Baseflow water chemistry results, July 2019 – June 2020. All concentrations are in units of mg/L unless indicated.

Baseflow Date	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC002																
7/29/2019	1	0.34	1.4	<0.05	<0.5	<0.05	59	0.6	0.2	11	<5	613	1.4	170	128	8.43
8/22/2019	<1	<0.3	1.4	<0.05	0.5	<0.05	<2	0.6	<1	6	<5	147	1.9	162	119	1.35
9/24/2019	<1	0.31	1.5	<0.05	<0.5	<0.05	2	0.7	0.09	11	<5	687	1.5	181	136	1.76
10/15/2019	<1	0.16	1.6	<0.07	0.6	<0.05	3	<2	<1	11	<5	83.6	2.2	174	129	1.23
11/22/2019	1	<0.3	1.5	<0.05	0.5	0.008	4	<2	<1	9	<5	50.4	2	162	125	1.06
12/4/2019	<1	0.08	1.5	<0.05	0.4	0.008	3	<2	<1	15	<5	60.2	1.9	150	105	1.56
1/7/2020	1	0.37	1.6	<0.05	0.3	0.007	<2	0.3	<1	13	<5	18.5	1.9	156	118	1.52
2/18/2020	<1	0.22	1.7	<0.05	0.4	0.01	2	<2	0.09	10	<5	8.5	2.1	150	119	1.51
3/10/2020	<1	0.18	1.7	<0.05	0.3	0.03	<2	0.3	<1	7	<5	66.3	2	148	115	1.32
4/23/2020	2	0.47	1.6	<0.05	0.4	<0.05	<2	<2	<1	7	<5	98.7	2	158	123	1.22
5/12/2020	<1	0.45	1.4	<0.05	0.4	0.01	2	0.4	<1	8	<5	133	1.8	150	119	2.14
6/19/2020	<1	0.23	1.4	<0.05	0.5	0.03	3	1	0.1	12	<5	435	1.9	160	106	1.88
Station WC003																
7/29/2019	<1	<0.3	1.1	<0.05	<0.5	<0.05	5	<2	0.1	8	<5	308	1.1	185	157	3.17
8/22/2019	<1	<0.3	1	<0.05	0.7	<0.05	3	0.7	0.08	12	<5	218	1.7	179	144	3.36
9/24/2019	<1	<0.3	0.9	<0.05	<0.5	<0.05	3	0.7	0.09	18	<5	1990	0.9	284	158	4.18
10/15/2019	<1	0.07	0.9	<0.07	0.6	0.01	13	0.4	<1	16	<5	155	1.5	190	143	6.25
11/22/2019	2	<0.3	1	<0.05	0.5	<0.05	15	0.8	0.2	21	<5	37.9	1.5	176	149	5.59
12/4/2019	<1	<0.3	1	<0.05	0.4	<0.05	5	<2	<1	17	<5	365	1.4	155	119	1.97
1/7/2020	1	0.07	1.1	<0.05	0.4	0.008	<2	0.5	<1	14	<5	12.1	1.5	169	139	1.4
2/18/2020	<1	<0.3	1.2	<0.05	0.4	0.01	3	<2	<1	13	<5	127	1.6	178	141	2.13
3/10/2020	<1	0.08	1.1	<0.05	0.4	0.006	<2	0.7	0.06	17	<5	9.7	1.5	158	134	1.76
4/23/2020	1	0.1	1	<0.05	0.4	<0.05	<2	<2	<1	5	<5	21.3	1.4	156	139	1.65
5/12/2020	<1	0.07	1	<0.05	0.4	0.01	<2	0.5	<1	10	<5	345	1.4	154	137	2.3
6/19/2020	<1	0.09	0.9	<0.05	0.5	0.02	<2	0.9	0.1	22	<5	1300	1.4	178	134	2.4

Table 4-2. (Continued)

Baseflow Date	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophosphate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitrogen	Hardness	Chloride	Turbidity (NTU)
Station WC004																
7/29/2019	<1	<0.3	3.4	<0.05	<0.5	<0.05	8	<2	<1	15	<5	344	3.4	278	250	1.72
8/22/2019	<1	<0.3	3.3	<0.05	0.5	<0.05	<2	0.8	0.1	21	<5	162	3.8	312	267	0.69
9/24/2019	<1	<0.3	2.8	<0.05	<0.5	<0.05	<1	0.8	<1	20	<5	391	2.8	320	245	0.34
10/15/2019	<1	0.08	3.8	<0.07	0.5	<0.05	11	<2	<1	24	<5	249	4.3	373	307	0.73
11/22/2019	<0.9	<0.3	3.4	<0.05	0.4	<0.05	8	0.9	0.1	35	<5	102	3.8	294	262	0.87
12/4/2019	<1	<0.3	2.8	<0.05	0.4	<0.05	<2	<2	<1	24	<5	122	3.2	246	227	0.3
1/7/2020	2	0.06	2.8	<0.05	0.5	0.007	<2	0.8	<1	25	<5	30.1	3.3	231	212	0.56
2/18/2020	<1	<0.3	2.8	<0.05	0.4	0.009	<2	<2	<1	19	<5	15.8	3.2	242	235	0.58
3/10/2020	<1	0.06	3	<0.05	0.3	<0.05	<2	0.8	<1	25	<5	178	3.3	244	229	0.65
4/23/2020	1	0.06	2.8	<0.05	0.3	<0.05	<2	<2	<1	15	<5	44.3	3.1	220	224	0.36
5/12/2020	<1	<0.3	2.4	<0.05	0.3	0.01	<2	0.6	<1	18	<5	75.4	2.7	193	205	0.94
6/19/2020	<1	0.05	2.3	<0.05	0.6	0.02	2	1	0.06	21	<5	1990	2.9	218	204	1.02

4.3 BASEFLOW MEAN AND STORM EVENT MEAN CONCENTRATION DATA

EMC values for each parameter were calculated at each station for each storm event (Table 4-3). Average annual baseflow concentration and storm EMC values were calculated for each pollutant at each station (Table 4-4). Average concentration data computed for storm and baseflows over the course of a year were used to characterize pollutant concentrations during average baseflow conditions or an average stormflow event (Figures 4-1 through 4-6). Total annual and seasonal baseflow mean concentrations, storm EMCs, and loads for each pollutant are presented in Appendix D and Appendix E, respectively.

Under baseflow conditions, average concentrations of combined nitrate plus nitrite, chloride, zinc, and copper were highest at Station WC004 compared to the other two stations downstream. *E. coli* concentrations were higher at Station WC004 than at Station WC002, as in years past, but were lower than the *E. coli* concentrations found at Station WC003. Concentrations of ammonia were disproportionally highest at Station WC002, at a level nearly six times higher than the next highest mean concentration. The higher concentrations of *E. coli* and combined nitrate plus nitrite at Station WC004 may indicate a continued nutrient and septic input in the vicinity of the station. The excessive levels of ammonia at Station WC002 may indicate the presence of a chronic problem such as leakage from a sanitary sewage line. Higher average chloride values may be the result of mobilization of chloride in groundwater as a result of runoff from legacy deicing compound application at the Festival of Bel Air Shopping Center and along Route 24. Samples collected at Station WC003 had the highest average concentrations of total TKN and lead during baseflow conditions. Station WC002 samples had the highest average concentrations of BOD, ammonia, and TSS at baseflow conditions.

Under stormflow conditions, average EMCs were highest at Station WC004 for lead, zinc, and *E. coli* (Figures 4-1 through 4-6), which may be the result of washing of accumulated pollutants in runoff from paved parking areas at Festival of Bel Air and the roadbed of Route 24. Average EMCs for BOD, ammonia, nitrate plus nitrite, TKN, total phosphorus, and copper were highest at Station WC002. At Station WC003, only TSS and chloride were highest of the three stations. All average stormflow EMCs exceeded corresponding baseflow mean concentrations at all stations except combined nitrate plus nitrite and chloride. Average EMCs of all pollutants at all stations were lower than Maryland and national average values (Table 4-4).

Time-series plots of the annual average concentrations of pollutants measured from 2010 to FY2020 are shown in Figure 4-7 through Figure 4-15 and are presented to characterize change, on an annual basis, in pollutant concentrations as restoration projects were implemented in the watershed. Plots of average annual storm EMCs and baseflow MCs (with individual non-detect concentrations set to zero) are presented for the following pollutants: nitrate-nitrite, TKN, total phosphorus, TSS, copper, zinc, lead, ammonia, and BOD. Note that data from the shortened reporting period comprising the first six months of calendar year 2015 were not included in the plots.

Table 4-3. Storm event mean concentration results (mg/L except where indicated), July 2019 – June 2020 (non-detects set to zero).

Storm Date	Rainfall (inches)	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophos-phate	TKN	Total P	TSS	Chloride	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)
Station WC002												
10/7/2019	0.39	1.25	0.05	0.80	0.00	1.47	0.16	48.85	74.79	7.26	1.25	42.24
10/9/2019	0.18	2.08	0.13	0.57	0.00	0.72	0.04	6.60	61.68	2.46	0.00	21.71
10/22/2019	0.72	3.55	0.17	0.58	0.00	0.92	0.09	22.46	50.68	6.23	0.71	29.91
12/9/2019	0.87	4.02	0.04	0.40	0.00	0.60	0.10	12.61	15.48	5.49	0.00	31.40
2/5/2020	0.17	1.21	0.14	1.11	0.00	0.50	0.02	0.00	129.17	1.57	0.00	13.65
2/12/2020	0.24	1.70	0.09	1.19	0.00	0.48	0.02	3.44	87.68	2.00	0.00	12.10
4/12/2020	3.65	4.63	0.21	0.44	0.05	1.58	0.34	63.28	16.39	16.89	3.40	66.50
6/20/2020	1.57	3.22	0.18	0.49	0.02	0.98	0.12	19.16	26.79	7.44	0.12	26.23
Station WC003												
10/7/2019	0.39	0.00	0.00	0.52	0.00	1.08	0.08	27.36	71.57	5.02	0.41	28.55
10/9/2019	0.18	0.17	0.03	0.29	0.00	0.67	0.02	3.21	77.42	1.10	0.00	2.21
10/22/2019	0.72	2.79	0.00	0.31	0.01	0.96	0.10	30.87	26.05	8.24	1.50	38.65
12/9/2019	0.87	3.04	0.04	0.30	0.00	0.54	0.06	8.95	27.43	5.20	0.00	32.05
2/5/2020	0.17	0.42	0.03	0.88	0.00	0.50	0.01	2.24	172.16	2.00	0.00	14.21
2/12/2020	0.24	1.54	0.00	0.73	0.00	0.40	0.01	1.98	90.20	1.08	0.00	12.93
4/12/2020	3.65	3.56	0.15	0.33	0.02	1.05	0.16	60.40	19.00	13.65	2.00	37.62
6/20/2020	1.57	2.71	0.21	0.33	0.01	1.23	0.14	57.49	36.79	10.83	0.42	46.97
Station WC004												
10/7/2019	0.39	0.45	0.00	0.47	0.00	1.17	0.06	19.78	41.86	8.57	0.45	41.51
10/9/2019	0.18	1.43	0.00	0.31	0.00	0.74	0.02	3.05	39.76	2.78	0.00	28.63
10/22/2019	0.72	1.41	0.01	0.30	0.00	0.74	0.03	11.14	21.50	5.64	0.21	22.56
12/9/2019	0.87	2.43	0.17	0.26	0.00	0.59	0.04	5.32	15.62	5.46	0.21	44.29
2/5/2020	0.17	2.62	0.06	0.62	0.00	0.76	0.03	3.61	192.73	4.80	0.00	37.01
2/12/2020	0.24	2.00	0.03	0.77	0.01	0.55	0.04	69.33	79.44	5.95	4.42	46.33
4/12/2020	3.65	2.13	0.14	0.25	0.01	0.85	0.07	15.20	13.32	7.40	0.71	25.45
6/20/2020	1.57	1.84	0.33	0.37	0.01	0.69	0.04	9.27	25.50	5.20	0.00	21.80

Table 4-4. Average storm EMCs and baseflow mean concentrations, Wheel Creek Watershed, July 2019 – June 2020 (non-detects set to zero). All concentrations are in units of mg/L unless indicated.

Station	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Chlor-ide	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)
Storm Event Mean Concentrations													
WC002	2.71	0.13	0.70	0.01	0.91	0.11	22.05	57.83	6.17	0.69	30.47	0.00	691.74
WC003	1.78	0.06	0.46	0.01	0.80	0.07	24.06	65.08	5.89	0.54	26.65	0.00	726.07
WC004	1.79	0.09	0.42	0.00	0.76	0.04	17.09	53.71	5.73	0.75	33.45	0.00	913.29
MD avg[(a)]	14.44	N.R.	0.85	N.R.	1.94	0.33	66.57	N.R.	17.9	12.5	143.3	N.R.	N.R.
NSQD[(b)]	16.943	N.R.	1.587	N.R.	2.921	0.412	111.295	N.R.	42	41	250	2.759	N.R.
NURP[(c)]	9	N.R.	0.68	N.R.	1.5	0.33	100	N.R.	34	144	160	N.R.	N.R.
Baseflow Mean Concentrations													
WC002	0.42	0.23	1.53	0.00	0.36	0.01	6.50	120.17	0.33	0.04	10.00	0.00	200.10
WC003	0.33	0.04	1.02	0.00	0.39	0.01	3.92	141.17	0.43	0.05	14.42	0.00	407.42
WC004	0.25	0.03	2.97	0.00	0.35	0.00	2.42	238.92	0.48	0.02	21.83	0.00	308.63

N.R. = Reference data not available.
(a) = Maryland State average values from Bahr 1997.
(b) = National Stormwater Quality Database values for Maryland from Pitt 2008.
(c) = National Urban Runoff Program values from U.S. EPA 1983.

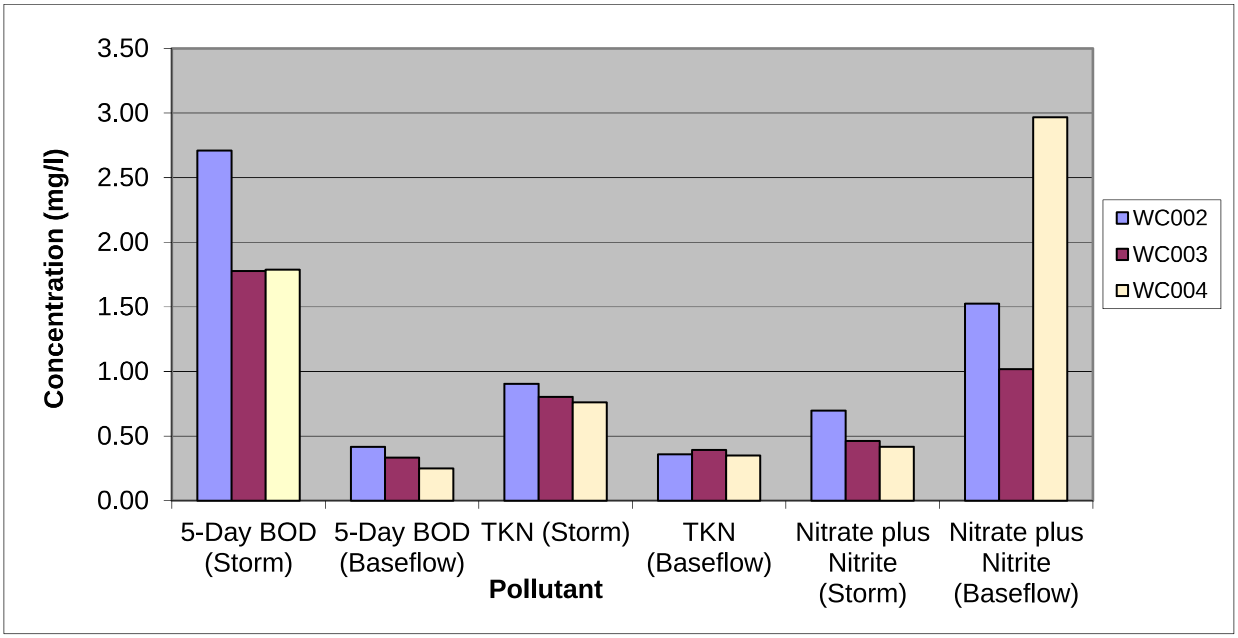

Figure 4-1. Nitrogen and 5-day BOD average storm event mean and baseflow mean concentrations in Wheel Creek, July 2019 – June 2020

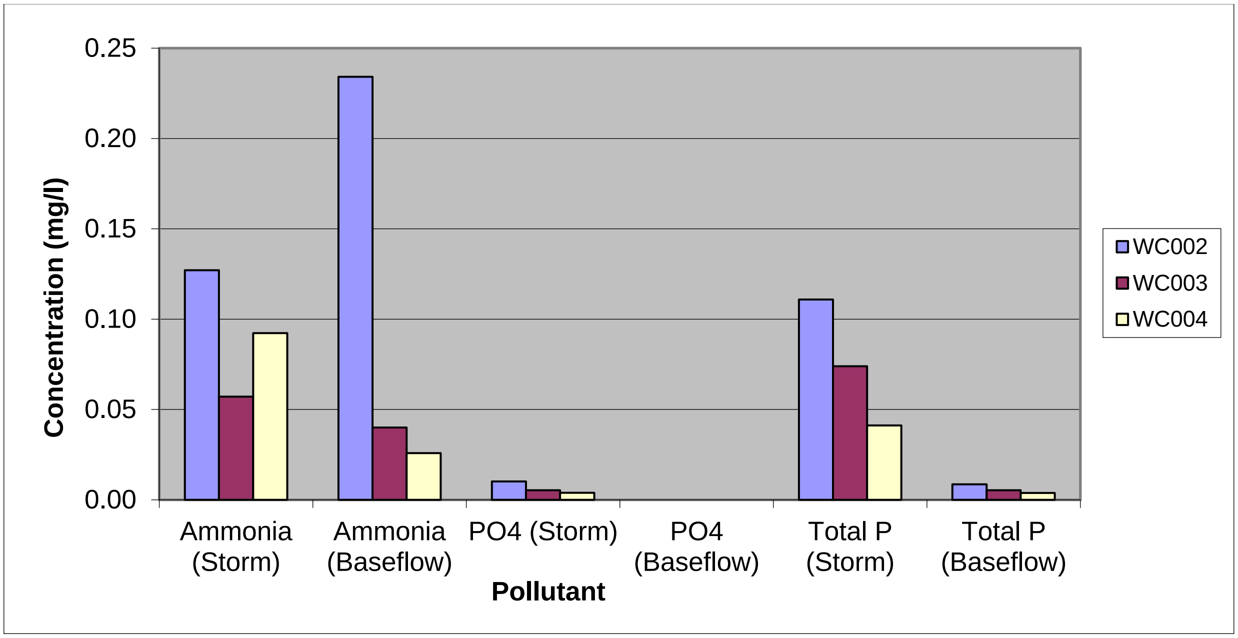

Figure 4-2. Ammonia and phosphorus average storm event mean and baseflow mean concentrations in Wheel Creek, July 2019 – June 2020

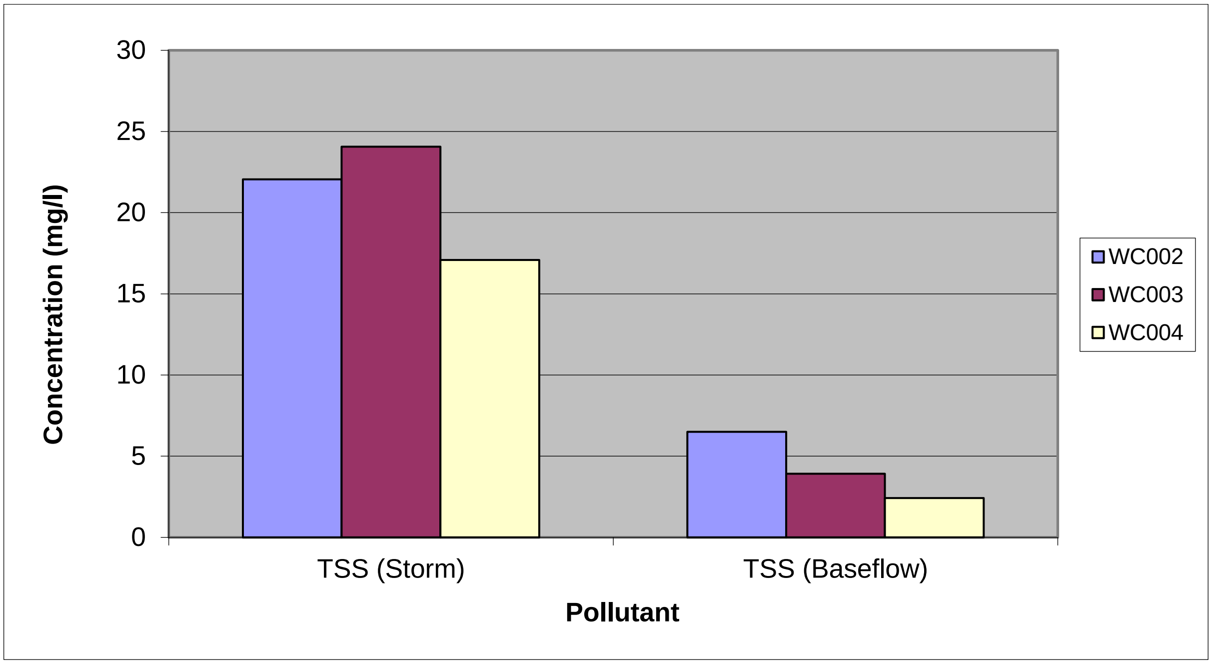

Figure 4-3. TSS average storm event and baseflow mean concentrations in Wheel Creek, July 2019 – June 2020

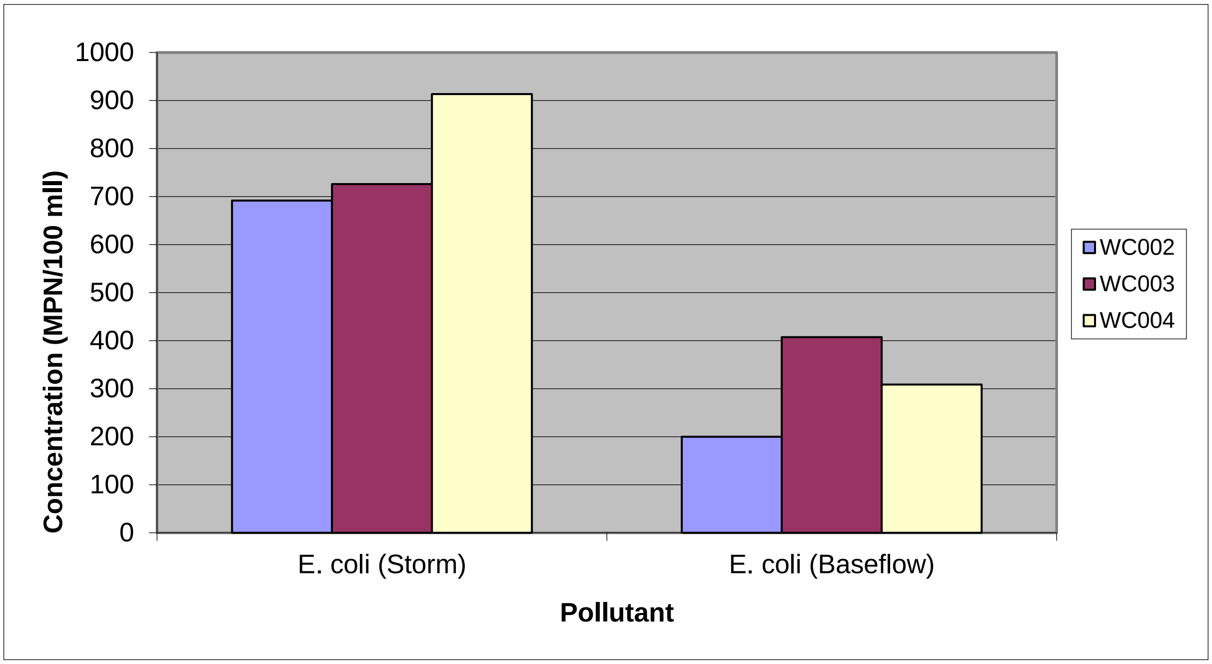

Figure 4-4. *E. coli* average storm and baseflow mean concentrations in Wheel Creek, July 2019 – June 2020

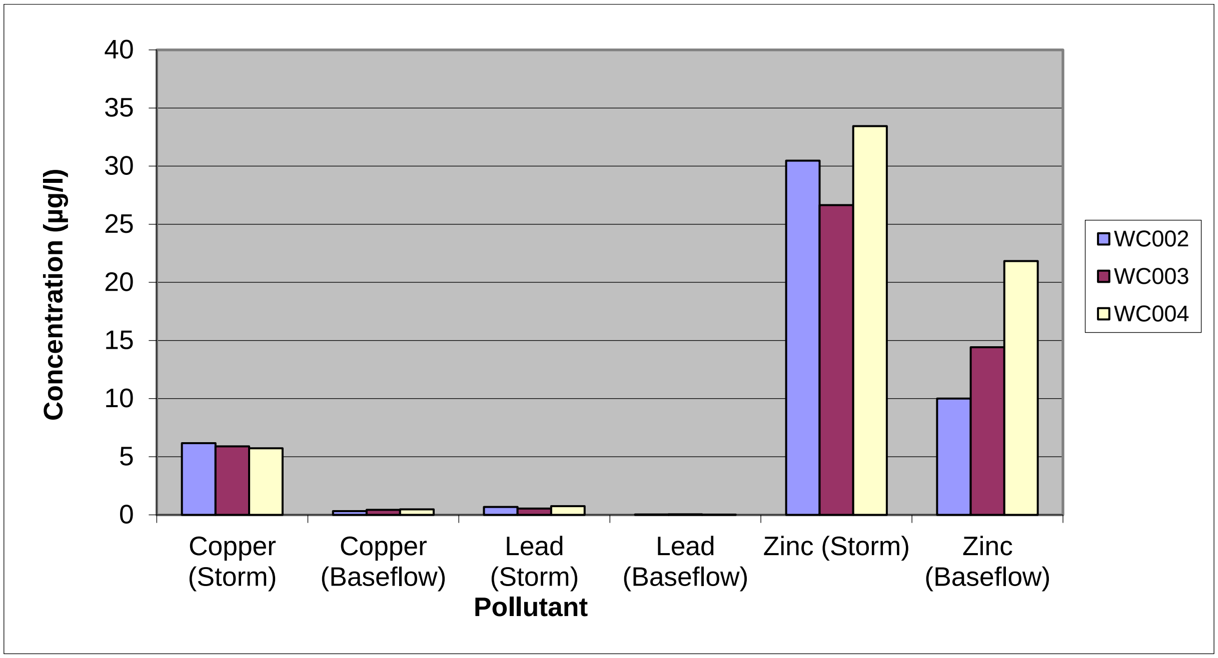

Figure 4-5. Metal average storm event mean and baseflow mean concentrations in Wheel Creek, July 2019 – June 2020

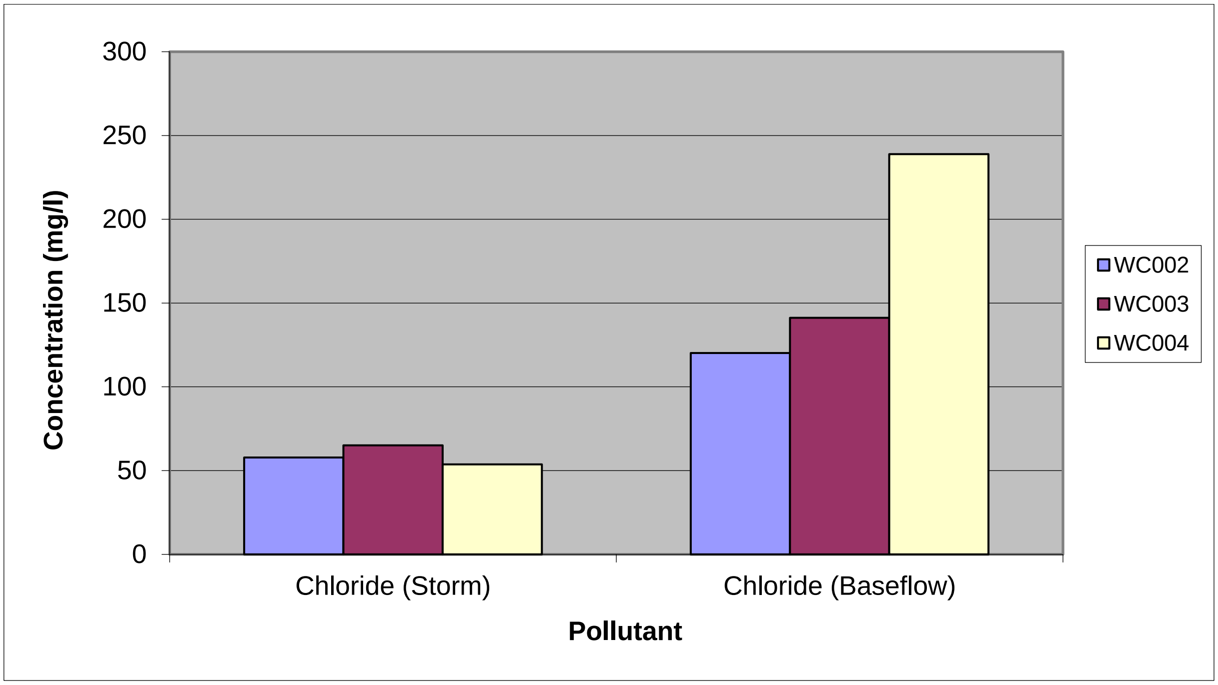

Figure 4-6. Chloride storm event mean and baseflow mean concentrations in Wheel Creek, July 2019 – June 2020

Visually, some of the plots show a potential change in long-term trend in annual concentration data that can be associated with completion of restoration projects in the watershed. For nitrate plus nitrite, while FY2020 showed a slight increase in baseflow MC at Station WC004, the prevailing trend continues gradually downward at all stations since approximately 2014, coinciding with the completion of most of the restoration projects. Storm EMCs for several of the parameters, such as total phosphorus, TSS, copper, and BOD show signs of gradually increasing trend until approximately FY2017 and then notably falling in FY2018 through FY2020. Average storm EMCs for TKN behaved similarly in FY2018 but rebounded in FY2019 and FY2020 at all stations. Conversely, EMCs for ammonia gradually decreased through FY2017, then abruptly increased in FY2018 before falling in FY2019. Average storm EMCs and baseflow MCs increased again for ammonia at all three stations in FY2020, and dramatically for baseflow at Station WC002, but not for baseflow MC at Station WC003. Lead EMCs for two out of three stations declined in FY2019 and FY2020, and zinc EMCs declined at all three stations in FY2020 compared to the previous year. The time series data may indicate that the restoration efforts, in concert, are having the desired effect of reducing parameters under specific flow regimes except for ammonia, total phosphorus, and TKN. Continued monitoring is recommended to distinguish a permanent change in long-term pollutant concentrations.

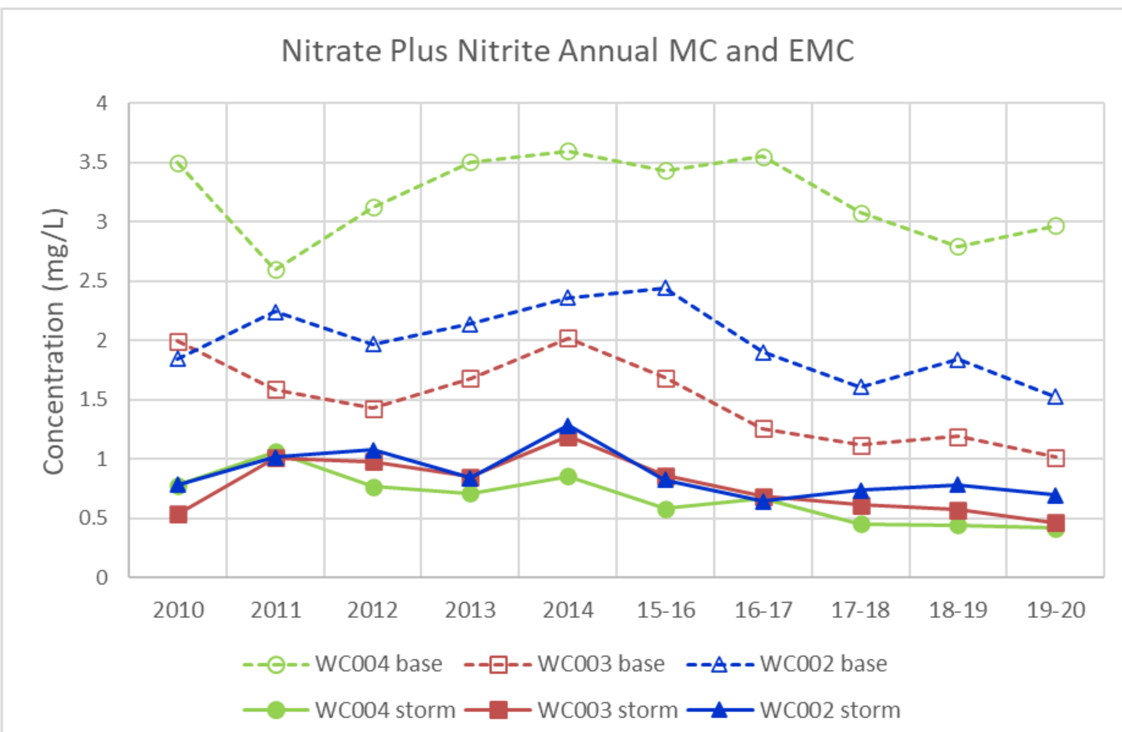

Figure 4-7. Time series plot of average annual baseflow MC and stormflow EMC for nitrate-nitrite (2010-FY2020)

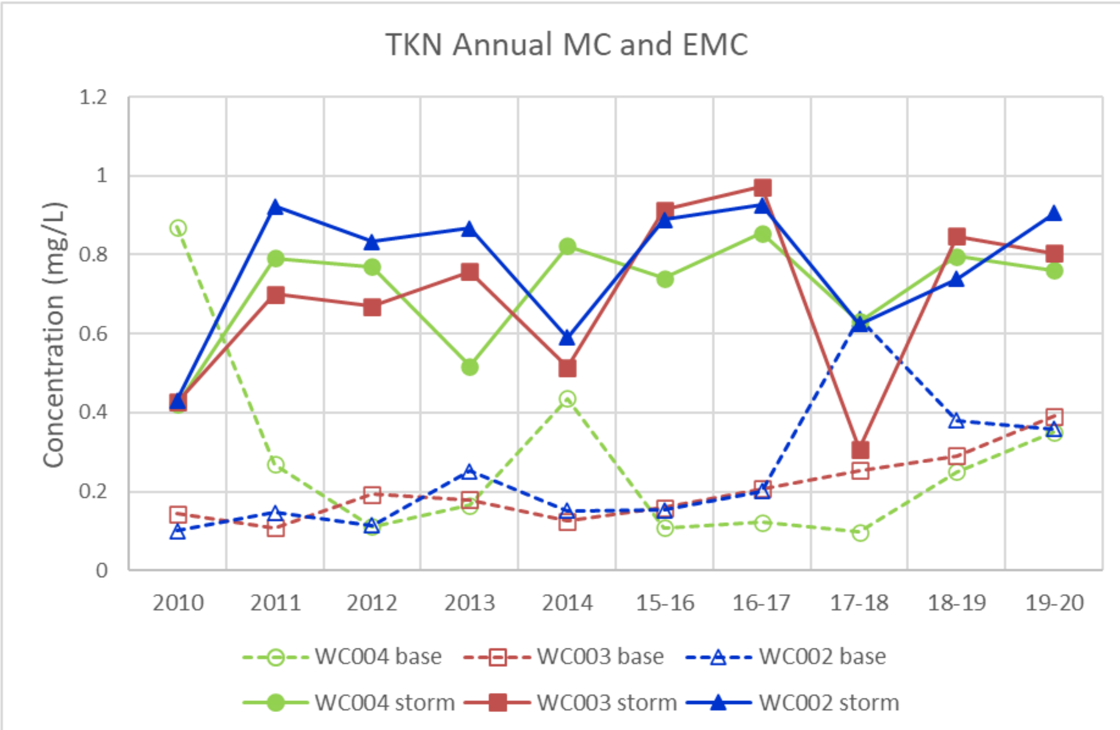

Figure 4-8. Time series plot of average annual baseflow MC and stormflow EMC for TKN (2010-FY2020)

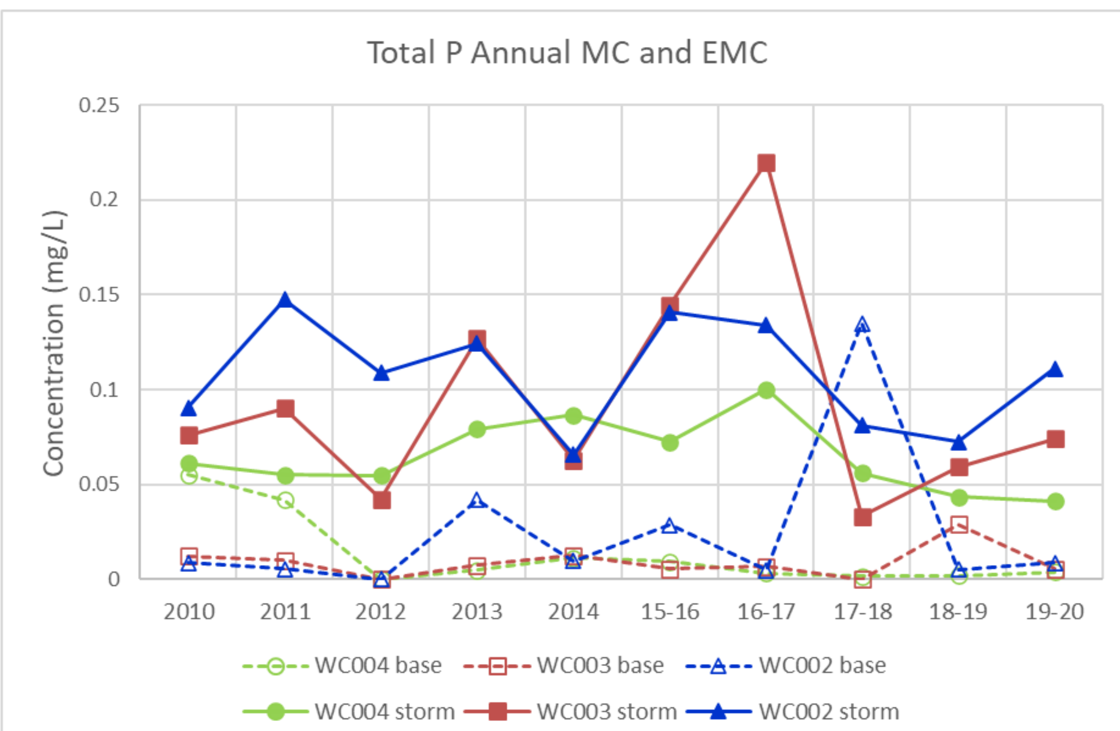

Figure 4-9. Time series plot of average annual baseflow MC and stormflow EMC for total phosphorus (2010-FY2020)

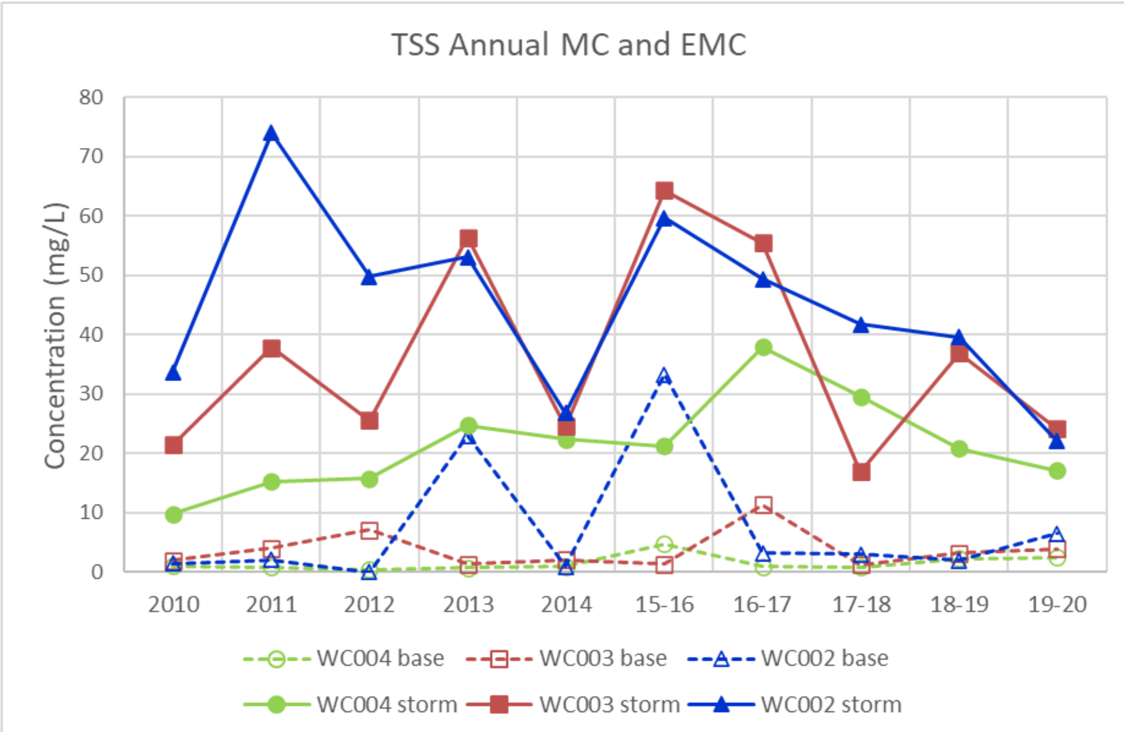

Figure 4-10. Time series plot of average annual baseflow MC and stormflow EMC for TSS (2010-FY2020)

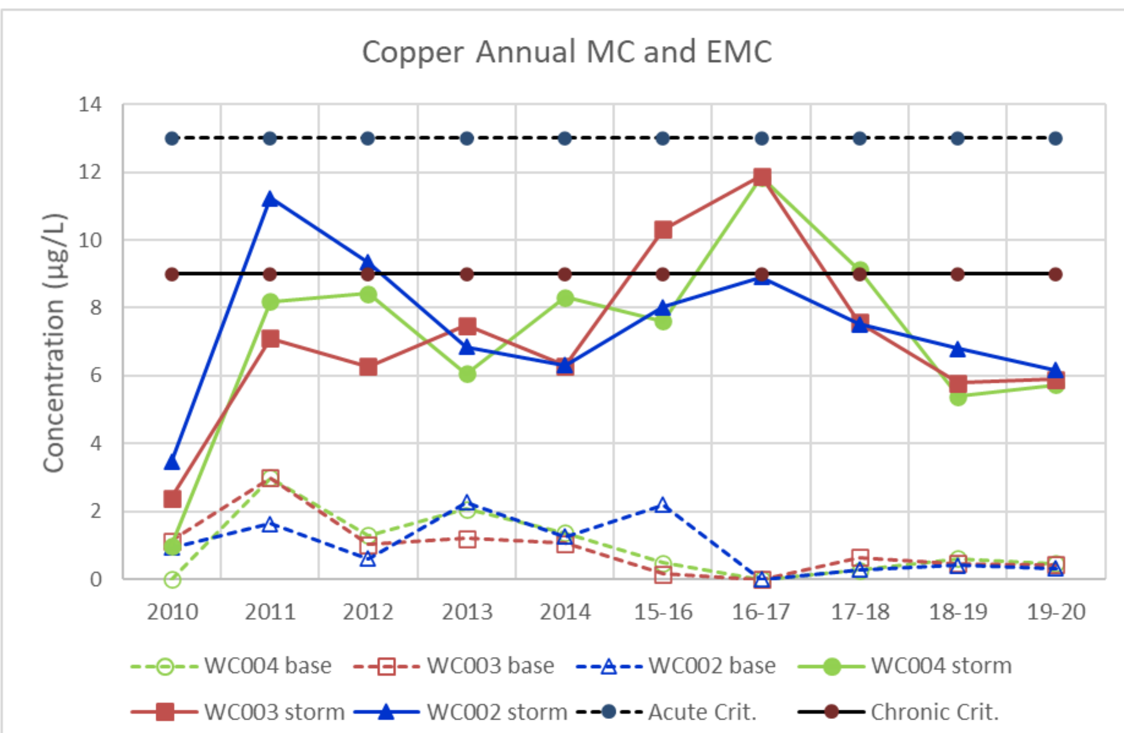

Figure 4-11. Time series plot of average annual baseflow MC and stormflow EMC for copper (2010-FY2020)

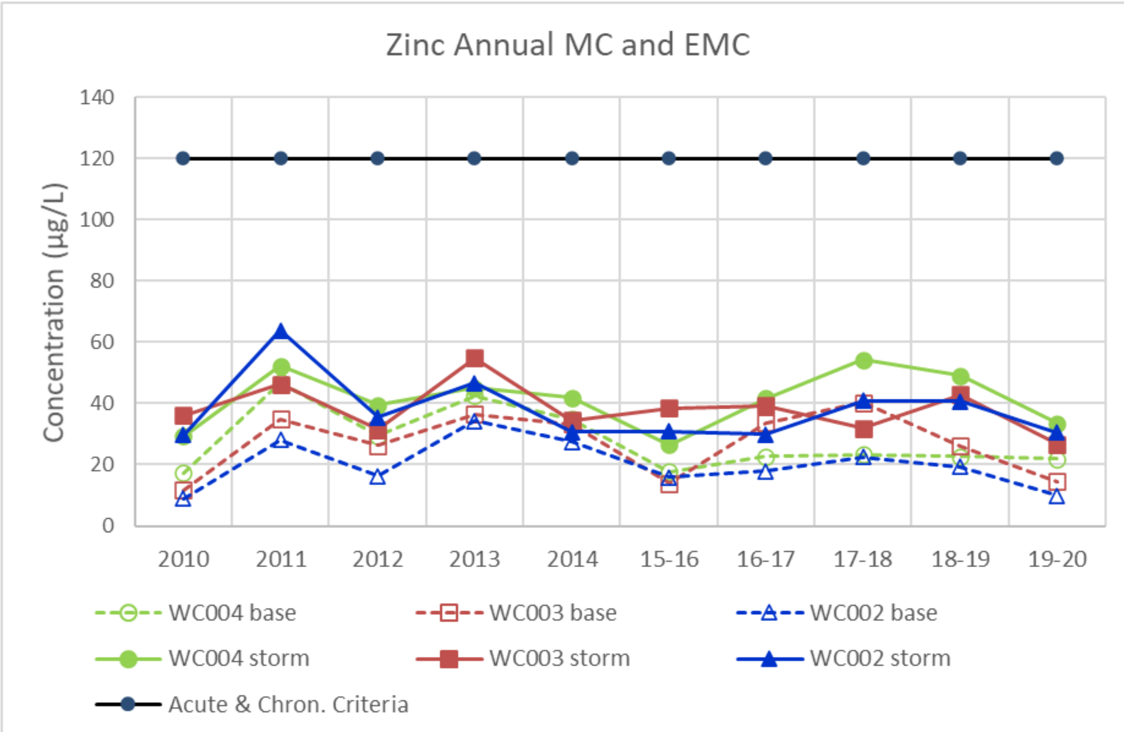

Figure 4-12. Time series plot of average annual baseflow MC and stormflow EMC for zinc (2010-FY2020)

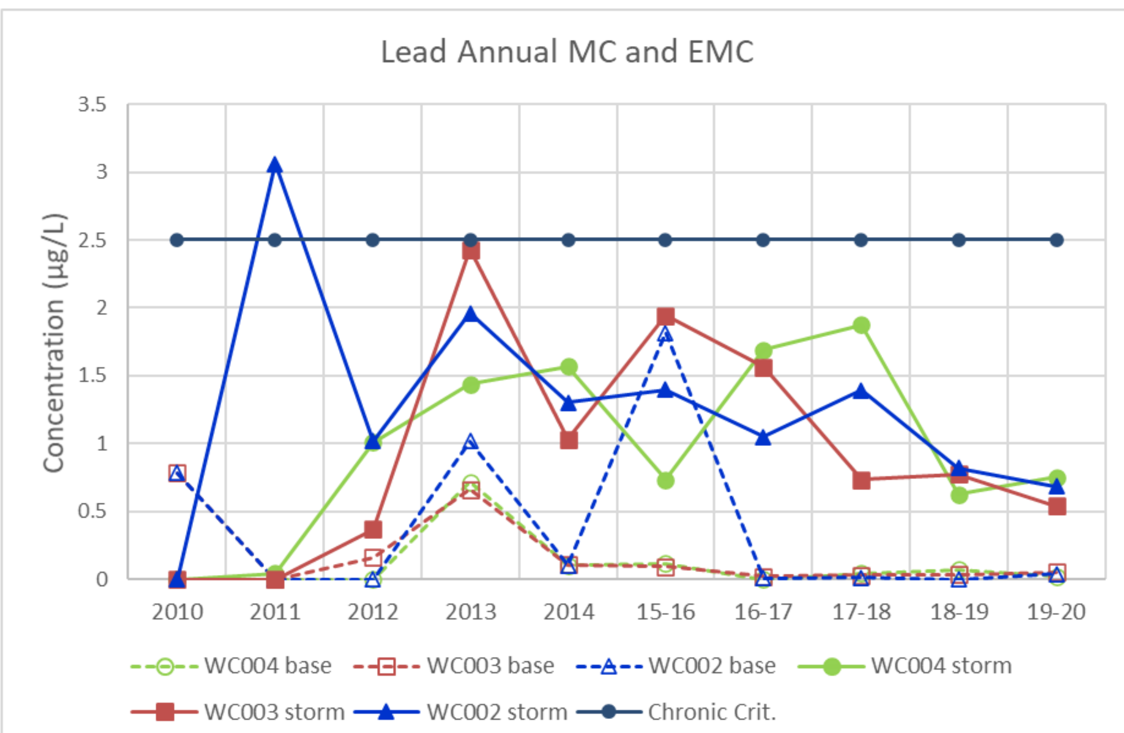

Figure 4-13. Time series plot of average annual baseflow MC and stormflow EMC for lead (2010-FY2020). Note: the acute criterion is not shown to maintain small scale.

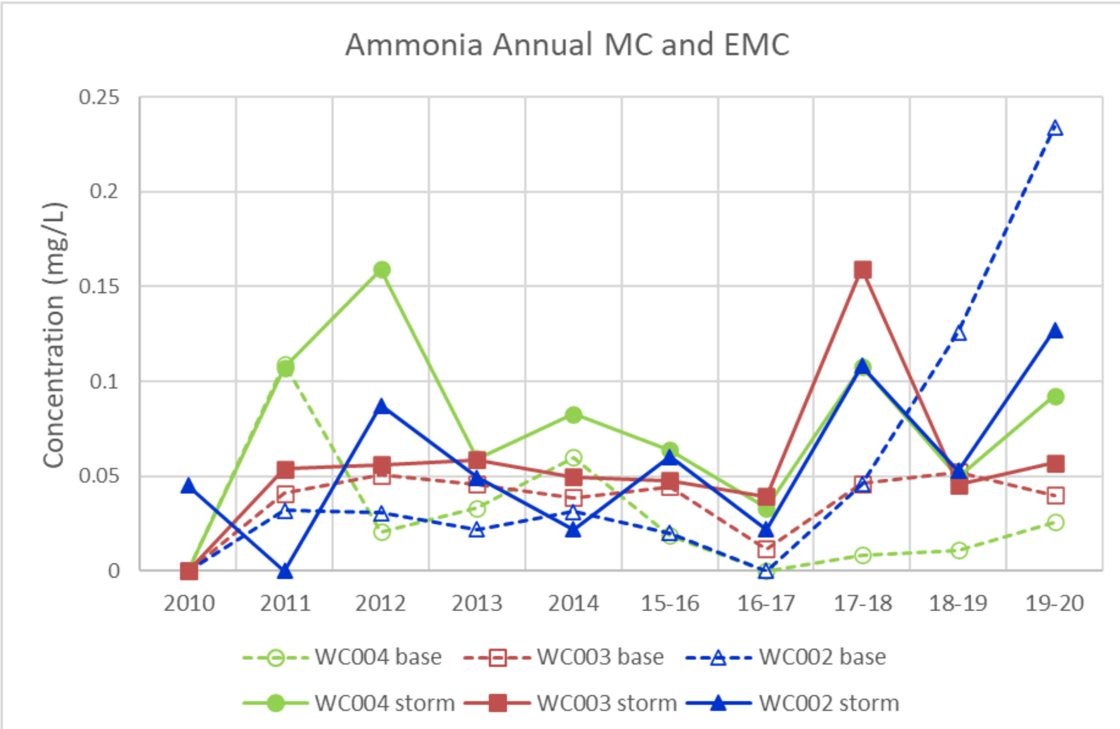

Figure 4-14. Time series plot of average annual baseflow MC and stormflow MC for ammonia (2010-FY2020)

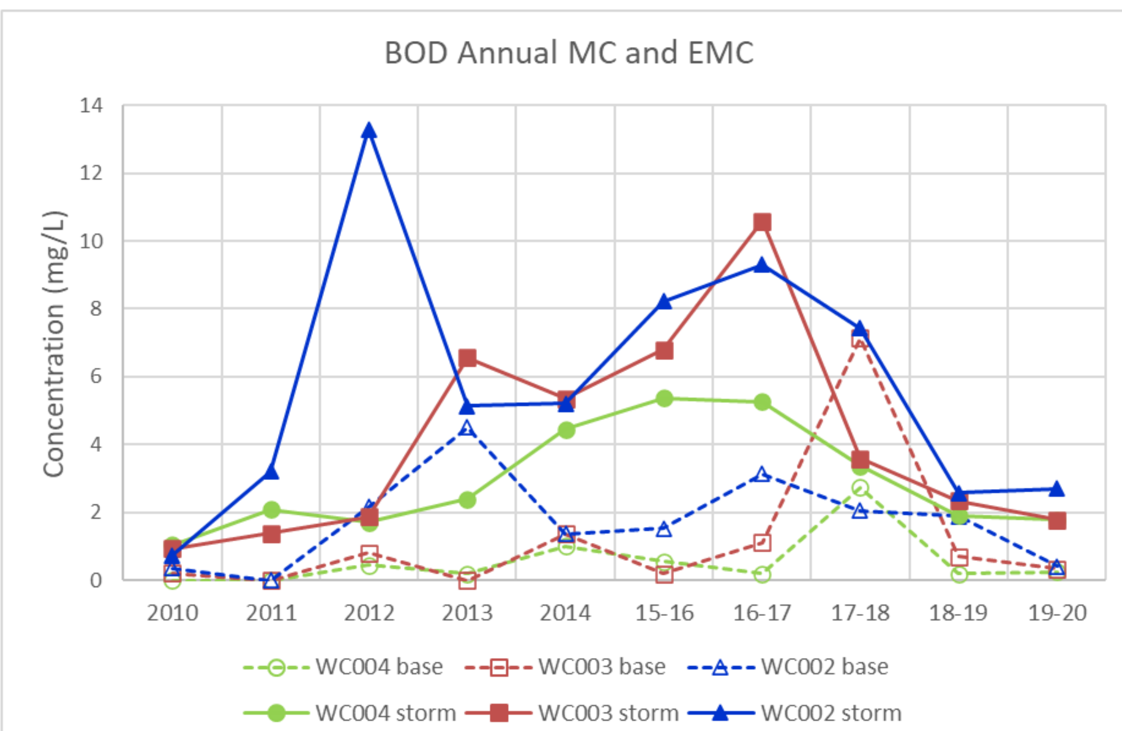

Figure 4-15. Time series plot of average annual baseflow MC and stormflow MC for BOD (2010-FY2020)

4.4 STORMFLOW POLLUTANT LOADING DATA

Pollutant loads for individual storms at each station were calculated from individual stormflow event mean concentration data (Table 4-5). Pollutant load represents the quantity of pollutant, in pounds, that was transported in the stream during the event. For discussion purposes, an average load was determined for each pollutant at each station for storms monitored from July 2019 through June 2020.

When comparing stations, average storm loads were highest at Station WC002 for all parameters (Table 4-6). Average loads were lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

4.5 SEDIMENT TRANSPORT SAMPLING RESULTS

A summary of suspended sediment transport data for Stations WC002, WC003, and WC004 and suspended sediment transport curves for Stations WC002 and WC003 are presented below. The discharges associated with each sediment sample were approximated from flow rate data recorded at the time when the stage at which the samplers filled, as shown by stage loggers attached to the siphon samplers, was achieved.

During eight sampling events from July 2019 to June 2020, a total of 17 samples were collected at Station WC002 (Table 4-7), 17 samples were collected at Station WC003 (Table 4-8), and 14 samples were collected at Station WC004 (Table 4-9). Note that bottles are numbered in sequence from the lowest to the highest point in the water column. Suspended sediment concentrations ranged from 3.6 to 59.3 mg/L at Station WC002, 9 to 458 mg/L at Station WC003, and 5.6 to 87.2 mg/L at Station WC004. By request by Harford County on April 7, 2020, SSC sampling was suspended for the storms monitored on April 14, 2020 and June 22, 2020 while the County negotiated a new laboratory contract.

Sediment transport curves were created for each station using concentrations of suspended sediment in samples and corresponding flow rate values for storms monitored from July 2019 through June 2020. A sediment transport curve was prepared for WC004 though only eight bottles could be correlated to level data recorded by the onboard level logger in this siphon sampler and assigned a flow rate value. Results at Station WC002 showed a moderate correlation between discharge and suspended sediment concentration (r^2 = 0.63; Figure 4-16). Average instantaneous discharges for each sample were approximately the same as those reported in the previous year. The sediment transport curve prepared for Station WC003 showed a low correlation between discharge and suspended sediment concentration (r^2 = 0.30; Figure 4-17). The sediment concentration correlation at Station WC003 was similar to that reported last year, with slightly lower concentrations per discharge noted. Results at Station WC004 showed a low correlation between discharge and suspended sediment concentration (r^2 = 0.21; Figure 4-18).

Table 4-5. Storm event pollutant loadings (lbs per event), July 2019 – June 2020 (non-detects set to zero).

Storm Date	Discharge (cf)	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
Station WC002												
10/7/2019	60,688	4.75	0.20	3.04	0.00	5.55	0.62	185.08	283.36	0.028	0.005	0.160
10/9/2019	81,285	10.55	0.65	2.87	0.00	3.67	0.19	33.48	312.98	0.012	0.000	0.110
10/22/2019	401,036	88.97	4.33	14.47	0.10	23.00	2.22	562.29	1268.92	0.156	0.018	0.749
12/9/2019	452,448	113.55	1.18	11.44	0.00	16.95	2.74	356.04	437.20	0.155	0.000	0.887
2/5/2020	53,174	4.00	0.45	3.67	0.01	1.66	0.05	0.00	428.78	0.005	0.000	0.045
2/12/2020	54,268	5.77	0.31	4.03	0.00	1.62	0.06	11.65	297.05	0.007	0.000	0.041
4/12/2020	4,023,690	1163.92	52.63	110.50	13.32	397.79	86.39	15894.41	4118.00	4.242	0.854	16.705
6/20/2020	576,309	116.00	6.60	17.68	0.72	35.19	4.44	689.46	963.78	0.268	0.004	0.944
Station WC003												
10/7/2019	25,699	0.00	0.00	0.84	0.00	1.74	0.13	43.89	114.83	0.008	0.001	0.046
10/9/2019	12,719	0.13	0.02	0.23	0.00	0.53	0.01	2.55	61.47	0.001	0.000	0.002
10/22/2019	39,737	6.92	0.00	0.76	0.04	2.38	0.26	76.57	64.63	0.020	0.004	0.096
12/9/2019	20,121	3.82	0.05	0.38	0.00	0.68	0.08	11.24	34.45	0.007	0.000	0.040
2/5/2020	22,832	0.59	0.04	1.25	0.00	0.71	0.02	3.20	245.39	0.003	0.000	0.020
2/12/2020	31,197	3.00	0.00	1.43	0.00	0.78	0.03	3.86	175.66	0.002	0.000	0.025
4/12/2020	1,251,100	277.98	11.75	25.73	1.41	81.90	12.66	4717.63	1483.86	1.066	0.156	2.938
6/20/2020	181,006	30.60	2.38	3.71	0.11	13.94	1.57	649.58	415.69	0.122	0.005	0.531
Station WC004												
10/7/2019	23,363	0.65	0.00	0.68	0.00	1.70	0.08	28.86	61.06	0.013	0.001	0.061
10/9/2019	9,905	0.88	0.00	0.19	0.00	0.45	0.01	1.88	24.58	0.002	0.000	0.018
10/22/2019	50,644	4.46	0.04	0.96	0.00	2.35	0.11	35.23	67.96	0.018	0.001	0.071
12/9/2019	70,952	10.75	0.76	1.14	0.00	2.59	0.16	23.55	69.17	0.024	0.001	0.196
2/5/2020	15,441	2.52	0.05	0.60	0.00	0.73	0.03	3.48	185.78	0.005	0.000	0.036
2/12/2020	27,955	3.49	0.05	1.35	0.02	0.96	0.07	120.99	138.63	0.010	0.008	0.081
4/12/2020	354,615	47.11	3.07	5.56	0.32	18.85	1.56	336.52	294.91	0.164	0.016	0.563
6/20/2020	86,088	9.91	1.78	2.00	0.04	3.72	0.23	49.79	137.03	0.028	0.000	0.117

Table 4-6. Average storm pollutant loads (lbs/event), Wheel Creek monitoring, July 2019 – June 2020 (non-detects set to zero)

Station	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
WC002	188.44	8.29	20.96	1.77	60.68	12.09	2216.55	1013.76	0.61	0.11	2.46
WC003	40.38	1.78	4.29	0.19	12.83	1.84	688.57	324.50	0.15	0.02	0.46
WC004	9.97	0.72	1.56	0.05	3.92	0.28	75.04	122.39	0.03	0.00	0.14

Table 4-7. Suspended sediment results at Station WC002, July 2019 – June 2020

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)
7-Oct-19	1	30.9	1.19	9-Dec-19	1	13.8	0.73
7-Oct-19	2	12.1	1.91	9-Dec-19	2	12.2	1.64
9-Oct-19	1	24.6	1.26	9-Dec-19	3	17.5	5.80
9-Oct-19	2	14.3	2.40	9-Dec-19	4	21.5	14.76
22-Oct-19	1	15.5	0.74	5-Feb-20	1	5.6	1.26
22-Oct-19	2	32.1	1.23	5-Feb-20	2	15.0	N.R.
22-Oct-19	3	34.8	5.06	12-Feb-20	1	3.6	1.13
22-Oct-19	4	57.3	23.01	12-Feb-20	2	11.5	N.R.
22-Oct-19	5	59.3	42.64				

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Table 4-8. Suspended sediment results at Station WC003, July 2019 – June 2020

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)
7-Oct-19	1	178.0	0.28	22-Oct-19	6	199.0	3.65
7-Oct-19	2	458.0	1.07	9-Dec-19	1	13.9	0.12
9-Oct-19	1	43.5	0.11	9-Dec-19	2	206.0	0.11
9-Oct-19	2	74.0	0.32	9-Dec-19	3	22.2	0.11
22-Oct-19	1	41.4	0.07	9-Dec-19	4	23.8	0.17
22-Oct-19	2	29.8	0.07	9-Dec-19	5	27.1	0.64
22-Oct-19	3	58.0	0.17	5-Feb-20	1	22.7	N.R.
22-Oct-19	4	66.2	0.60	12-Feb-20	1	9.0	0.17
22-Oct-19	5	106.0	1.64				

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Table 4-9. Suspended sediment results at Station WC004, July 2019 – June 2020							
Date	**Bottle Number**	**Suspended Sediment (mg/L)**	**Discharge**	**Date**	**Bottle Number**	**Suspended Sediment (mg/L)**	**Discharge**
7-Oct-19	1	68.3	0.95	22-Oct-19	5	87.2	N.R.
7-Oct-19	2	25.8	N.R.	9-Dec-19	1	10.0	0.36
9-Oct-19	1	28.0	0.43	9-Dec-19	2	14.5	1.57
22-Oct-19	1	20.0	0.27	9-Dec-19	3	7.1	N.R.
22-Oct-19	2	34.1	1.20	9-Dec-19	4	5.6	N.R.
22-Oct-19	3	47.7	N.R.	5-Feb-20	1	9.5	0.52
22-Oct-19	4	18.0	N.R.	12-Feb-20	1	9.5	0.26
N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.							

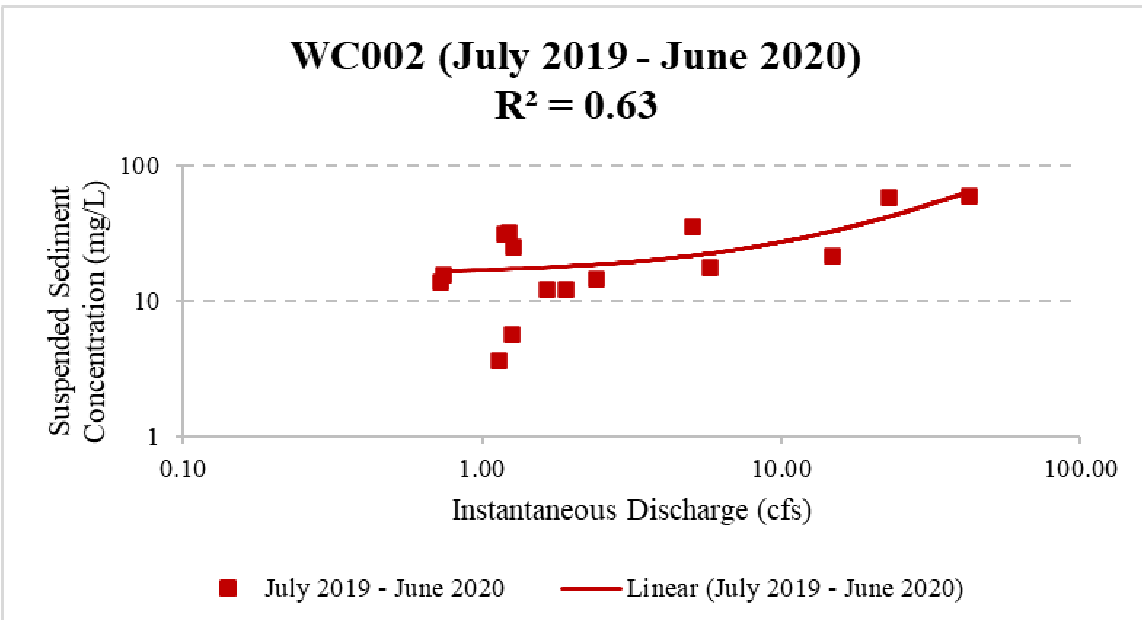

Figure 4-16. Suspended sediment curve for Wheel Creek Station 002 (July 2019 – June 2020)

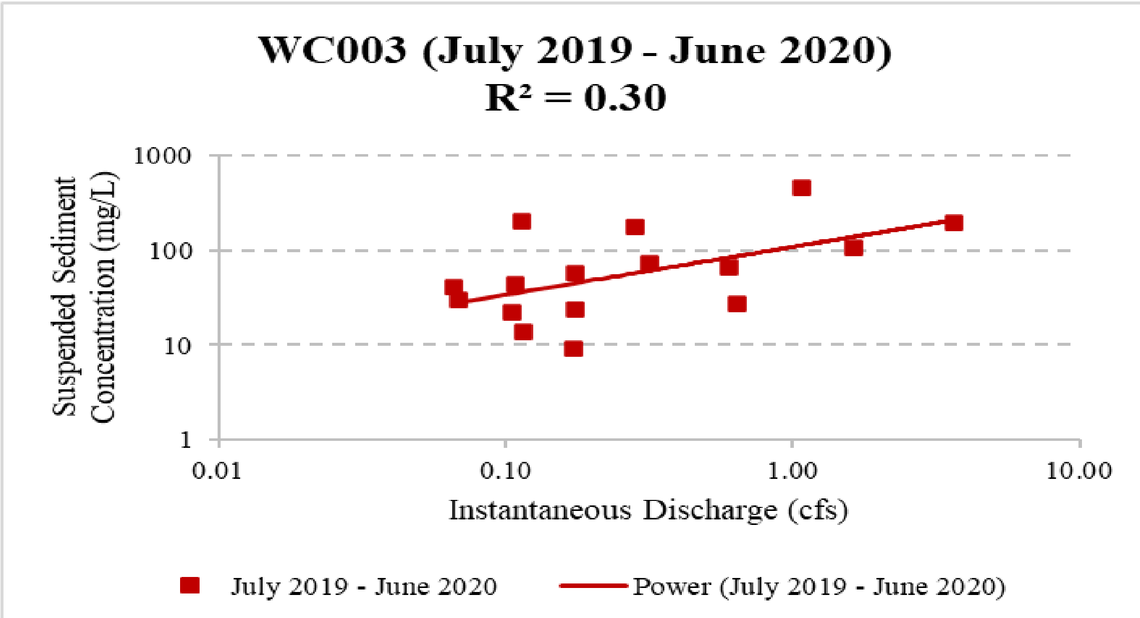

Figure 4-17. Suspended sediment curve for Wheel Creek Station 003 (July 2019 – June 2020)

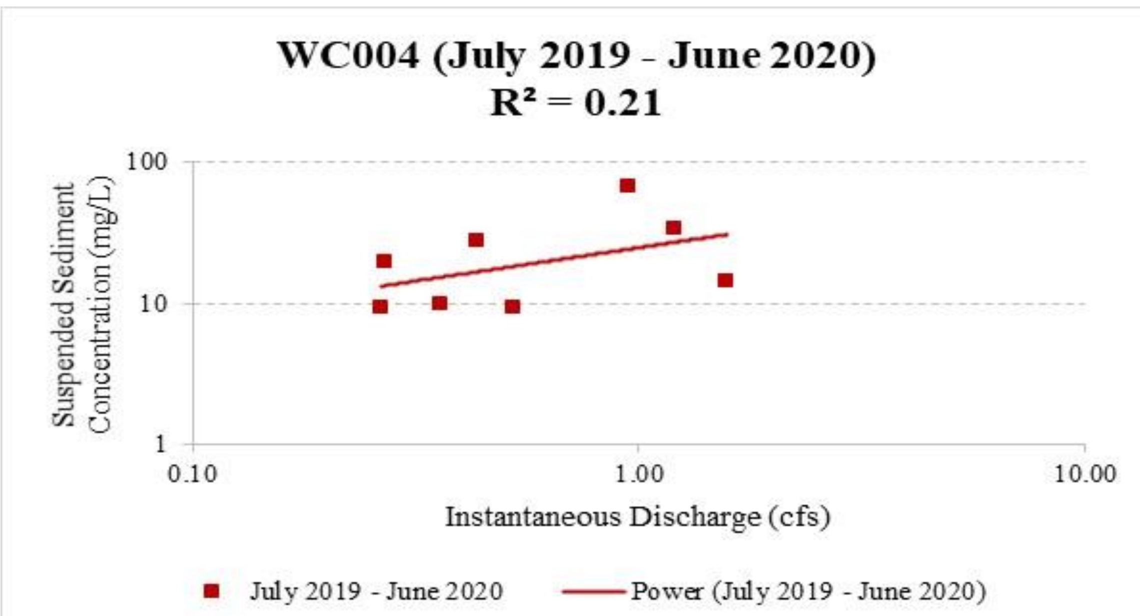

Figure 4-18. Suspended sediment curve for Wheel Creek Station 003 (July 2019 – June 2020)

The arithmetic mean of stormflow-associated suspended sediment concentrations, by station, exceeded corresponding average annual EMCs of TSS, suggesting that TSS results underestimate the actual transport of sediment during storms (Figure 4-19).

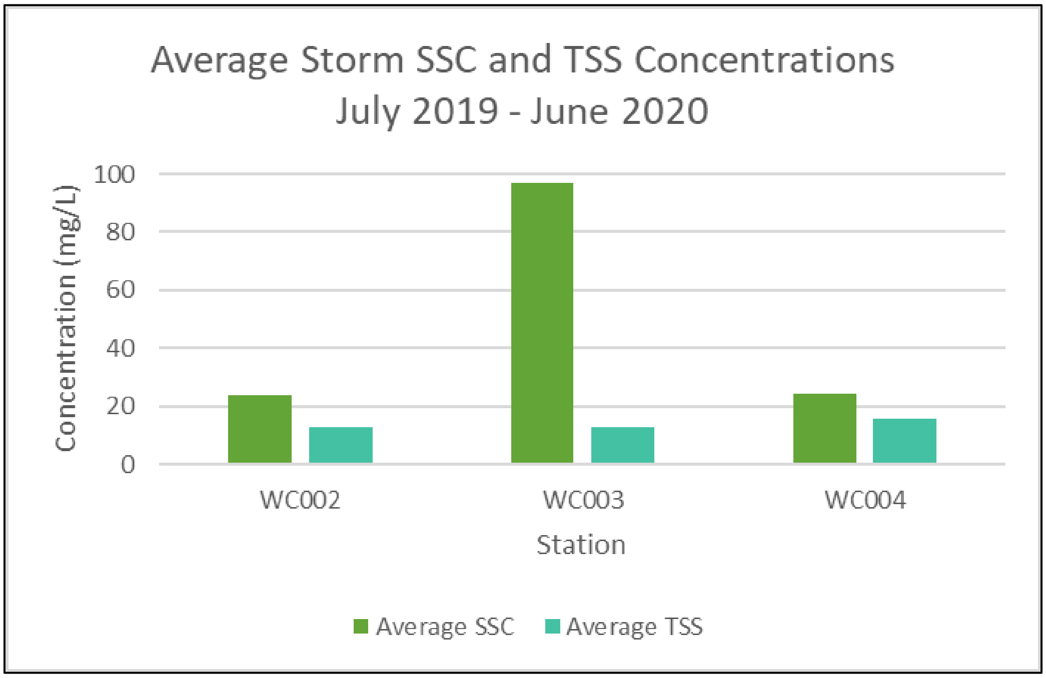

Figure 4-19. Average SSC and TSS concentrations in stormwater runoff (July 2019 – June 2020)

4.6 MONITORING PROBLEMS IDENTIFIED IN 2019-2020

4.6.1 Storm Events

During the October 9-10, 2019 storm event, the field staff discovered that the rain gauge was not logging rain data due to the internal cord blocking the tipping mechanism. The USGS rain gauge was also offline during this period; therefore, Versar used a local Weather Underground rain gauge, Bel Air South for the rain total for the storm event.

During the February 5-6, 2020 storm event, the bubbler line detached from the sensor at Station WC002. To approximate discharge during the storm event for compositing, field staff used the flow data and hydrograph from Station WC003.

During the February 12-13, 2020 storm event at Station WC003, the field crew returned to the station at 1:30 p.m. to manually collect a falling limb grab sample due to the stream levels being too high during the initial composite.

During the April 12-13 storm event at Stations WC002 and WC003, the field crew noticed that the bubbler line had become detached during the storm event In order to composite the storm, Versar field staff used the WC004 hydrograph and discharge information to assist in the compositing of the other two sites.

During the June 19-22, 2020 storm event, the field crew noticed that the bubbler had become detached from the sensor at the WC002 station due to a large limb that washed down the pipe during the storm. The Versar field crew re-attached the bubbler line and used the WC003 storm graph and discrete volumes to assist with the storm composite. No grab sample was taken at any part of the storm due to the timing of the event and the lack of opportunity for expedient delivery to the laboratory.

4.6.2 Continuous Stage Logging

The Solinst level loggers at each station were downloaded monthly. Episodes of sensor drift due to presence of sediment after storm flows and leaf debris in the fall have been noted. The level loggers occasionally accumulate sediment in the sensor holes, which needs to be removed. Leaf debris buildup in the channels causes a temporary backwater condition, causing heightened stage and artificially inflated flow rate readings. Adjustments to correct for the drift and leaf buildup were performed to improve the flow record.

In the winter, there were several months when the Solinst level loggers were removed from the stream due to cold weather and risk of damage to sensors from ice buildup. To reduce data gaps, ISCO bubbler flowmeters were installed at each site when the Solinst instruments were temporarily removed. Bubbler flowmeters are less prone to damage due to ice buildup around the sensor.

To account for data gaps, the following protocols were used to complete the stage records. All data from the Solinst level loggers were aggregated, and anomalous data encountered during data offloads and logger swapping were manually interpolated with the surrounding stage data. The level logger data were shifted to match observed actual staff gauge readings, and linear drift corrections were applied to correct periods of sensor drift. ISCO flowmeter data were also shifted to match staff gauge observations and Solinst level logger data; the ISCO level data were used when Solinst level loggers were offline.

4.7 COMPARISON OF PRE- AND POST-RESTORATION CONDITIONS

4.7.1 Comparison of Pollutant Ratios Between Stations WC002 and WC003

For this evaluation, a comparison of the ratios (in percent) of average pollutant concentrations and annual loads between Station WC003 and Station WC002 was employed to determine the benefit, in terms of pollution reduction, of restoration projects in the mainstem and in the middle branch between Station WC003 and Station WC002.

Total Annual Load

For the purpose of comparison, samples collected in 2010 and 2011 were treated as fully "pre-restoration" and those collected in FY2017-2020 were treated as fully "post-restoration." If the ratio of pollutant load between the upstream station (WC003) and downstream station

(WC002) during post-restoration conditions was less than the baseline ratio during pre-restoration conditions, then it may be concluded that the restoration projects reduced loading between the stations. Total loads and ratios are presented in Table 4-10. For comparison, intermediate post-restoration results using data collected in 2014, when no construction was in progress in the study area, are provided as in Jones et al. (2016).

In terms of total annual load, the ratios of the downstream station (WC002) to the upstream station (WC003) for nutrients were greater during post-restoration conditions than during pre-restoration conditions. Lead, copper, zinc, BOD, and TSS ratios were lower during the post-restoration phase, indicating that the restoration between the stations succeeded in reducing pollutant loads for these pollutants.

Storm EMCs

The ratios of average EMCs of pollutants during storm events captured during pre-restoration conditions were compared to the ratios of average EMCs for storms captured during post-restoration conditions. The average EMCs during these periods, and comparisons between periods, are provided in Table 4-11.

For all pollutants except ammonia, the average storm EMCs at the downstream station exceeded those at the upstream during pre-restoration; however, none of the differences were significant. After completion of restoration projects, only the average storm EMC of copper was less than at the upstream. Total nitrogen, TSS, BOD, and lead at the downstream station, conversely, were substantially higher than at the upstream station, though only the difference for total nitrogen was significant. The change in ratios suggests that the restoration in the contributing subwatersheds has reduced pollutant concentrations at Station WC002 under stormflow conditions for all parameters except for total nitrogen and ammonia.

Baseflow MCs

The ratios of average baseflow MCs of pollutants during pre-restoration conditions were compared to the ratios of average baseflow MCs during post-restoration conditions. The average MCs during these periods, and comparisons between periods, are provided in Table 4-12.

During pre-restoration phase baseflow conditions, total phosphorus, TSS, ammonia, copper, and zinc concentrations at the upstream station exceeded those at the downstream station, with TSS and zinc significant. Concentrations of BOD and total nitrogen were higher at the downstream station. After restoration, only BOD and zinc showed improvement in terms of lowering ratios between the upstream and downstream stations, with zinc showing a significant decrease. For the remaining parameters, concentrations at the downstream station became greater in relation to the upstream station, with total nitrogen and ammonia showing significant increases. The significantly higher ammonia concentrations at Station WC002 may be due to contributions of ammonia from a potential sanitary sewage source; however, average *E. coli* concentrations were lowest at Station WC002 and showed no correlation to ammonia concentrations, contrary to what could be expected from sanitary sewer inputs. Ammonia may be more easily reported since it is more mobile than *E. coli*, and *E. Coli* may be taken out of the water by soils.

Table 4-10. Comparison of Pre-Restoration and Post-Restoration Total Annual Loads

Phase	Total Load (lbs)		Ratio
	WC002	WC003	
Total Nitrogen			
Pre-Restoration (2010-2011)	7,258	1,905	73.8%
Post-Restoration (2014)	6,958	1,307	81.2%
Post-Restoration (FY 2017-20)	19,144	4,147	78.3%
Total Phosphorus			
Pre-Restoration (2010-2011)	281.8	73.9	73.8%
Post-Restoration (2014)	171.5	33.4	80.5%
Post-Restoration (FY 2017-20)	841.0	186.5	77.8%
TSS			
Pre-Restoration (2010-2011)	126,203	26,438	79.1%
Post-Restoration (2014)	67,237	12,413	81.5%
Post-Restoration (FY 2017-20)	232,958	73,145	68.6%
Ammonia			
Pre-Restoration (2010-2011)	72.4	32.1	55.7%
Post-Restoration (2014)	83.3	32.7	60.7%
Post-Restoration (FY 2017-20)	1,002.9	205.2	79.5%
BOD			
Pre-Restoration (2010-2011)	4,914	1,030	79.0%
Post-Restoration (2014)	14,168	2,918	79.4%
Post-Restoration (FY 2017-20)	36,114	9,906	72.6%
Copper			
Pre-Restoration (2010-2011)	19.2	4.9	74.3%
Post-Restoration (2014)	16.8	3.3	80.3%
Post-Restoration (FY 2017-20)	43.3	16.2	62.7%
Lead			
Pre-Restoration (2010-2011)	4.4	0.2	96.3%
Post-Restoration (2014)	3.3	0.5	84.1%
Post-Restoration (FY 2017-20)	5.8	1.8	68.5%
Zinc			
Pre-Restoration (2010-2011)	137.9	43.7	68.3%
Post-Restoration (2014)	101.1	24.2	76.1%
Post-Restoration (FY 2017-20)	306.5	104.2	66.0%

Table 4-11. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)				
Pollutant (mg/L)	**Station**		**Ratio**	**t test p-value (two-tailed)**
	WC002	**WC003**		
Pre-Restoration Conditions				
Total N	1.50	1.44	4%	0.60
Total P	0.104	0.073	30%	0.17
TSS	46.84	28.54	39%	0.13
Ammonia	0.017	0.030	-72%	0.48
BOD	2.400	1.585	34%	0.12
Copper	0.008	0.006	27%	0.17
Lead	0.479	0.000	100%	0.33
Zinc	0.043	0.038	11%	0.56
Post-Restoration Conditions				
Total N	1.57	1.26	20%	0.04
Total P	0.103	0.090	13%	0.57
TSS	40.56	31.96	21%	0.32
Ammonia	0.084	0.079	6%	0.85
BOD	5.812	4.306	26%	0.27
Copper	0.007	0.008	-3%	0.85
Lead	0.0011	0.0008	24%	0.41
Zinc	0.035	0.034	3%	0.83
Note: For all pollutants, $\alpha = 0.05$				

Table 4-12. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)				
Pollutant (mg/L)	**Station**		**Ratio**	**t test p-value (two-tailed)**
	WC002	**WC003**		
Pre-Restoration Conditions				
Total N	2.14	1.88	12%	0.22
Total P	0.006	0.040	-617%	0.28
TSS	1.38	3.36	-144%	0.04
Ammonia	0.016	0.030	-86%	0.19
BOD	0.900	0.387	57%	0.25
Copper	0.001	0.002	-55%	0.23
Lead	0.0003	0.0003	0%	N/A
Zinc	0.017	0.021	-25%	0.01
Post-Restoration Conditions				
Total N	2.08	1.43	31%	<0.0001
Total P	0.037	0.010	74%	0.40
TSS	3.61	4.81	-33%	0.67
Ammonia	0.098	0.044	55%	0.02
BOD	1.940	2.152	-11%	0.89
Copper	0.0002	0.0004	-51%	0.33
Lead	0.0002	0.00003	82%	0.37
Zinc	0.017	0.028	-64%	<0.0001
Note: For all pollutants, $\alpha = 0.05$ N/A = not applicable				

4.7.2 Subwatershed-level Evaluation of Pollutant Removal Efficiency

For this evaluation, average storm EMCs and baseflow MCs calculated during pre-restoration conditions were compared to those calculated during post-restoration conditions at each of the three monitoring stations to compute efficiency. The pollutant removal efficiency is a straightforward method to determine the net overall benefit of restoration projects in the contributing subwatershed to each station.

Storm EMCs

The average storm EMCs of pollutants during storm events captured during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-13.

Table 4-13. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase: Pre-Restoration	Phase: Post-Restoration	Percent Efficiency	t test p-value (two-tailed)
Station WC002				
Total N	1.50	1.53	-2%	0.91
Total P	0.104	0.098	6%	0.83
TSS	46.84	38.68	17%	0.57
Ammonia	0.017	0.092	-436%	0.0004
BOD	2.400	5.121	-113%	0.10
Copper	0.008	0.007	7%	0.77
Lead	0.479	0.001	100%	0.33
Zinc	0.043	0.038	12%	0.49
Station WC003				
Total N	1.44	1.25	14%	0.24
Total P	0.073	0.066	9%	0.76
TSS	28.54	30.97	-8%	0.81
Ammonia	0.030	0.090	-203%	0.06
BOD	1.585	3.653	-130%	0.09
Copper	0.006	0.007	-26%	0.47
Lead	0.000	0.001	N/A	0.003
Zinc	0.038	0.036	7%	0.70
Station WC004				
Total N	1.55	1.27	18%	0.04
Total P	0.068	0.063	7%	0.66
TSS	18.42	25.73	-40%	0.10
Ammonia	0.093	0.069	26%	0.29
BOD	2.536	3.582	-41%	0.12
Copper	0.007	0.008	-15%	0.30
Lead	0.001	0.001	-20%	0.56
Zinc	0.043	0.040	7%	0.60

Note: For all pollutants, α = 0.05
N/A = not applicable

At Station WC002, EMCs of all parameters except total nitrogen, ammonia, and BOD were reduced from pre-restoration conditions. The reduction in lead was effectively 100%. The reductions in total phosphorus, TSS, copper, and zinc were lower, at 6%, 17%, 7%, and 12%, respectively. Ammonia and BOD increased dramatically, by 436% and 113% respectively, with the increase in ammonia being significant.

At Station WC003, stormflow total nitrogen, total phosphorus, and zinc decreased between pre-restoration and post-restoration conditions by 14%, 9%, and 7%, respectively. BOD, ammonia, and lead increased between pre- and post-restoration phases, with lead significant. Copper and TSS increased by 26% and 8%, respectively.

At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions, by 18%, 7%, 26%, and 7%, respectively, with nitrogen significant. Copper, lead, BOD, and TSS increased after completion of restoration activities.

Baseflow MCs

The average baseflow MCs of pollutants during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-14.

At Station WC002 only baseflow total nitrogen, copper, and lead MCs were reduced after completion of restoration projects in the contributing subwatershed. The remaining parameters increased between pre-restoration and post-restoration by between 2% for zinc and over 7 times for total phosphorus and ammonia, with ammonia showing a significant increase. Baseflow concentrations of TSS and BOD increased by 176% and 61%, respectively.

At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced pollutants by efficiencies ranging from 23% for TSS to 88% for lead, with total nitrogen significant. As has been the case elsewhere and under both flow regimes, BOD dramatically increased nearly six-fold, though not significantly. Ammonia and zinc increased by 59% and 34%, respectively.

At Station WC004, baseflow efficiency results were the least ambiguous, with six of eight parameters reduced between pre-restoration conditions and post-restoration, with significant reductions for copper and zinc. Only TSS (292%) and BOD (118%) were greater during post-restoration than pre-restoration.

4.8 LONG-TERM TREND ANALYSIS OF WATER CHEMISTRY DATA

The time-series statistical tests performed on baseflow concentration and individual storm EMC data collected showed a significant downward trend for baseflow nitrate plus nitrite at Station WC003 and a significant downward trend for storm flow nitrate plus nitrite and baseflow copper at Station WC004. Several constituents have significantly increased over time, such as baseflow TSS at Stations WC002 and WC004, storm flow ammonia at Stations WC002 and WC003, baseflow BOD at Station WC003, baseflow lead at Station WC003, and baseflow total phosphorus at Station WC002. While increases in baseflow TSS concentrations over time are unexpected, possible contributors to increases in TSS concentrations are increases in imperviousness upstream in the watershed, lingering effects from retrofit and restoration projects, or an overall increase in baseflow due to the restorations causing an increased transport of suspended sediments. Overall, the results were mixed, with only 21 of the 54 EMCs and MCs under all flow conditions at all stations becoming lower over time. A summary of test results, including coefficients and significance, for indicator parameters is presented in Table 4-15.

Table 4-14. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase: Pre-Restoration	Phase: Post-Restoration	Percent Efficiency	t test p-value (two-tailed)
Station WC002				
Total N	2.14	2.10	2%	0.85
Total P	0.006	0.049	-775%	0.33
TSS	1.38	3.80	-176%	0.19
Ammonia	0.016	0.128	-706%	0.001
BOD	0.900	1.445	-61%	0.43
Copper	0.001	0.0003	70%	0.09
Lead	0.0003	0.00002	94%	0.36
Zinc	0.017	0.017	-2%	0.92
Station WC003				
Total N	1.88	1.39	26%	0.03
Total P	0.040	0.010	76%	0.33
TSS	3.36	2.60	23%	0.47
Ammonia	0.030	0.047	-59%	0.44
BOD	0.387	2.683	-593%	0.28
Copper	0.002	0.0005	70%	0.07
Lead	0.0003	0.00004	88%	0.36
Zinc	0.021	0.028	-34%	0.14
Station WC004				
Total N	3.49	3.32	5%	0.47
Total P	0.017	0.004	77%	0.10
TSS	0.66	2.58	-292%	0.15
Ammonia	0.052	0.014	74%	0.05
BOD	0.353	0.768	-118%	0.35
Copper	0.002	0.0004	78%	<0.0001
Lead	0.0002	0.00007	57%	0.32
Zinc	0.037	0.022	39%	0.004

Note: For all pollutants, α = 0.05
N/A = not applicable

Table 4-15. Results of Kendall's Tau-b significance tests for indicator parameters (2010-FY2020)

Parameter	WC002		WC003		WC004	
	Storm	Baseflow	Storm	Baseflow	Storm	Baseflow
Nitrate + Nitrite	0.0282 (-)	0.0022 (-)	0.0038 (-)	< 0.0001 (-)	0.0013 (-)	N.S.
Total Kjeldahl Nitrogen	N.S.	0.0005 (+)	N.S.	0.0041 (+)	N.S.	N.S.
Total Phosphorus	N.S.	0.0287 (+)	N.S.	N.S.	N.S.	N.S.
TSS	N.S.	0.0013 (+)	N.S.	N.S.	N.S.	0.0071 (+)
Ammonia	0.0003 (+)	< 0.0001 (+)	0.0483 (+)	N.S.	N.S.	N.S.
BOD	N.S.	N.S.	N.S.	0.0128 (+)	N.S.	N.S.
Copper	N.S.	N.S.	N.S.	N.S.	N.S.	0.0224 (-)
Lead	N.S.	N.S.	N.S.	0.0427 (+)	N.S.	N.S.
Zinc	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Positive (+) symbols or orange shading indicate an increasing trend over time; negative (-) symbols or green shading indicate a decreasing trend over time
N.S. = not significant

5.0 CONCLUSIONS

In a cooperative effort, Harford County DPW, Versar, and USGS conducted water chemistry and long-term flow monitoring in the Wheel Creek watershed from July 1, 2019 through June 30, 2020. The monitoring effort included twelve baseflow sampling and eight wet weather sampling events with suspended sediment transport sampling (only six of the eight wet weather events had suspended sediment transport sampling due to contract negotiations between Harford Count DPW and the laboratory). Baseflow and stormflow monitoring consisted of sampling for suspended solids, copper, lead, zinc, BOD, ammonia, nitrate plus nitrite, chloride, orthophosphate, total phosphorous, TKN, turbidity, hardness, TPH, and *E. coli*.

5.1 SUMMARY OF MONITORING RESULTS

Federal and State reference values for certain nutrients were exceeded on several occasions, confirming detrimental stream chemistry impacts from development and changes in land use. Total nitrogen, calculated from the sum of nitrate plus nitrite and TKN, was present at concentrations exceeding the EPA reference values (0.69 mg/L) for both baseflow (all detected samples) and stormflow (all detected samples). For total phosphorus, none of the baseflow samples and 52.8% of the detectible results in stormflow samples were found to be above the corresponding EPA reference concentration (0.03656 mg/L). No reported chloride concentrations in stormflow samples exceeded the EPA acute criterion (860 mg/L), while 16.7% of baseflow samples exceeded the chronic criterion for chloride (230 mg/L).

All baseflow samples had detectable amounts of zinc but none exceeded the MDE chronic surface water criterion (120 µg/L). Of the stormflow samples, 94.4% had detectable concentrations of zinc, but none exceeded the MDE acute criterion (120 µg/L). All lead concentrations fell below the MDE acute criterion (65 µg/L) for stormflow and the chronic criterion (2.5 µg/L) for baseflow this monitoring period. Copper concentrations did not exceed the MDE chronic criterion (9 µg/L) in baseflow samples, while 5.6% of stormflow samples exceeded the acute criterion (13 µg/L).

E. coli bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 8.5 to 1,990 MPN/100ml. *E. coli* concentrations were equal to or greater than the maximum reportable result in 19.0% of stormflow grab samples, down from 33.3% in the 2018-2019 monitoring period. TPH was not detected above the reporting limit in any of the baseflow or stormflow grab samples collected at the monitoring stations.

Average baseflow concentrations of combined nitrate plus nitrite, chloride, copper, and zinc were highest at Station WC004 compared to the other two stations downstream. Samples collected at Station WC003 had the highest average concentrations of TKN, lead, and *E. coli* during baseflow conditions. Station WC002 samples had the highest average concentrations of BOD, ammonia, and TSS at baseflow. Average stormflow EMCs were highest at Station WC004 for lead, zinc, and *E. coli*. Average EMCs for BOD, ammonia, nitrate plus nitrite, TKN, total phosphorus, and copper were highest at Station WC002. At Station WC003, only TSS and chloride were highest of the three stations.

Average stormflow loads were highest at Station WC002 and lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Suspended sediment transport correlated moderately with discharge at Station WC002 ($r^2 = 0.63$) and showed a low correlation at Stations WC003 ($r^2 = 0.30$) and WC004 ($r^2 = 0.21$). As in past monitoring periods, the sediment results have correlated better with discharge at the station having the largest contributing watershed area.

5.2 SUMMARY OF RESTORATION EFFECTIVENESS

Comparisons of pre-restoration and post-restoration pollutant load and concentration data were performed to determine the overall benefit to watershed conditions as a result of the implementation of the several restoration projects. Restoration activity initiated in late summer 2012 and concluded in spring 2017, allowing a post-restoration body of data to be accumulated. Subwatershed-level and total watershed benefits were evaluated by leveraging the placement of monitoring stations in relation to the restoration projects and completion timelines. A summary of findings is provided below.

Time series plots of annual average EMCs and MCs for most parameters show post-restoration stabilization as well as a potential downward trend in long-term concentration that can be inferred to be associated with completion of restoration projects in the watershed. Generally falling trends, or reduced annual concentrations during the period after FY2017 and FY2018, and coinciding with or immediately after the conclusion of implementation of restoration projects, can be identified for TSS, copper, zinc, BOD, lead, and nitrate plus nitrite. Exceptions to this trend include ammonia, total phosphorus, and TKN, which during the past two monitoring years have been generally similar to or trending higher than pre- or during-construction conditions. Baseflow ammonia at Station WC002 has been trending dramatically upward, year over year, since FY2017, indicating a potentially significant input from an unusual source, such as a sanitary sewer line between Stations WC002 and WC003 or within commercial and residential areas around the mainstem upstream of Station WC002.

Comparing ratios of average concentrations and loads at Stations WC003 and WC002, determined first under pre-restoration conditions and then under post-restoration conditions, produced mixed results. Comparisons of load ratios identified only BOD, TSS, lead, zinc, and copper as being reduced by restoration. Concentration ratios suggest that the restoration in the contributing subwatersheds has reduced concentrations of total phosphorus, TSS, BOD, copper, lead, and zinc at Station WC002 under stormflow conditions. Considering baseflow mean concentrations, only BOD and zinc showed improvement in terms of lowering percentage differences between the upstream and downstream stations.

Directly comparing post-restoration concentrations (both storm and baseflow) to pre-restoration concentrations showed the following: At Station WC002, storm EMCs of total phosphorus, TSS, copper, lead, and zinc were reduced from pre-restoration conditions. At Station WC003, stormflow total nitrogen, total phosphorus, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC002 baseflow total nitrogen, copper, and lead MCs were reduced after completion of restoration projects in the contributing subwatershed. At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced total nitrogen, total phosphorus, TSS, copper, and lead. At Station WC004, baseflow efficiency results were the least ambiguous, with six of eight parameters reduced between pre-restoration conditions and post-restoration.

A summary of the results of tests of restoration effectiveness is provided in Table 5-1.

Table 5-1. Results of tests of restoration effectiveness (bullets indicate pollutant reduction between post- and pre-restoration conditions)

	Target Sub-watershed	Parameter							
		BOD	**Ammonia**	**Total P**	**TSS**	**Total N**	**Copper**	**Lead**	**Zinc**
Ratio Loads	WC002 below WC003	●			●		●	●	●
Ratio EMC	WC002 below WC003	●		●	●		●	●	●
Ratio MC	WC002 below WC003	●							●
Before After EMC	WC002			●	●		●	●	
Before After EMC	WC003			●		●			●
Before After EMC	WC004		●	●		●			●
Before After MC	WC002					●	●	●	
Before After MC	WC003			●	●	●	●	●	
Before After MC	WC004		●	●		●	●	●	●

The time-series statistical test performed on baseflow concentration and individual storm EMC data collected showed significant downward trends for baseflow nitrate plus nitrite at Stations WC002 and WC003, storm flow nitrate plus nitrite at all stations, and baseflow copper at Station WC004. Several constituents have significantly increased over time, such as baseflow TSS at Stations WC002 and WC004, storm flow ammonia at Stations WC002 and WC003, baseflow

BOD at Station WC003, and baseflow lead at Station WC003. Overall, the results were mixed, with only 21 of the 54 EMCs and MCs under all flow conditions at all stations becoming lower over time, but a greater total than in FY2019.

Concentration data show decreases in average annual concentrations of several parameters during the current monitoring period compared to the previous monitoring period (FY2019), which may indicate the continuing of lower trending concentrations as a result of implementation of restoration projects. Results of comparisons of post-restoration to pre-restoration concentrations show that effectiveness was broadest at Station WC004, followed by Stations WC003 and WC002, and mostly reflected in baseflow conditions. When comparing ratios of concentrations at Stations WC002 and WC003 to isolate restoration work in contributing watersheds between the two stations, concentrations in storm runoff have been reduced for eight of 16 parameters. The results of analysis of ratios of loads show benefits in five of eight parameters. Given that pollutant load is highly dependent on discharge volume, the variability in storm events that are monitored may increase the variability of load data and complicate the determination of load reduction benefit. The change in contractor laboratory during FY2019, and consequential change in reporting limits, may also affect the determination of restoration benefits when using water chemistry indicators.

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APPENDIX A

STORM EVENT SUMMARY REPORTS

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

OCTOBER 7-8, 2019

INTRODUCTION

Versar field staff traveled to the site on October 7 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 9:05 p.m. the evening of Monday, October 7. At the Wheel Creek Rain Gauge Station, 0.39 inches of rain was recorded for the duration of the storm.

On the morning of October 8, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on October 8 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on October 8. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on October 8 for analysis.

RESULTS

Hydrographs for the October 7-8 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the October 7-8 event are shown in Table A-5.

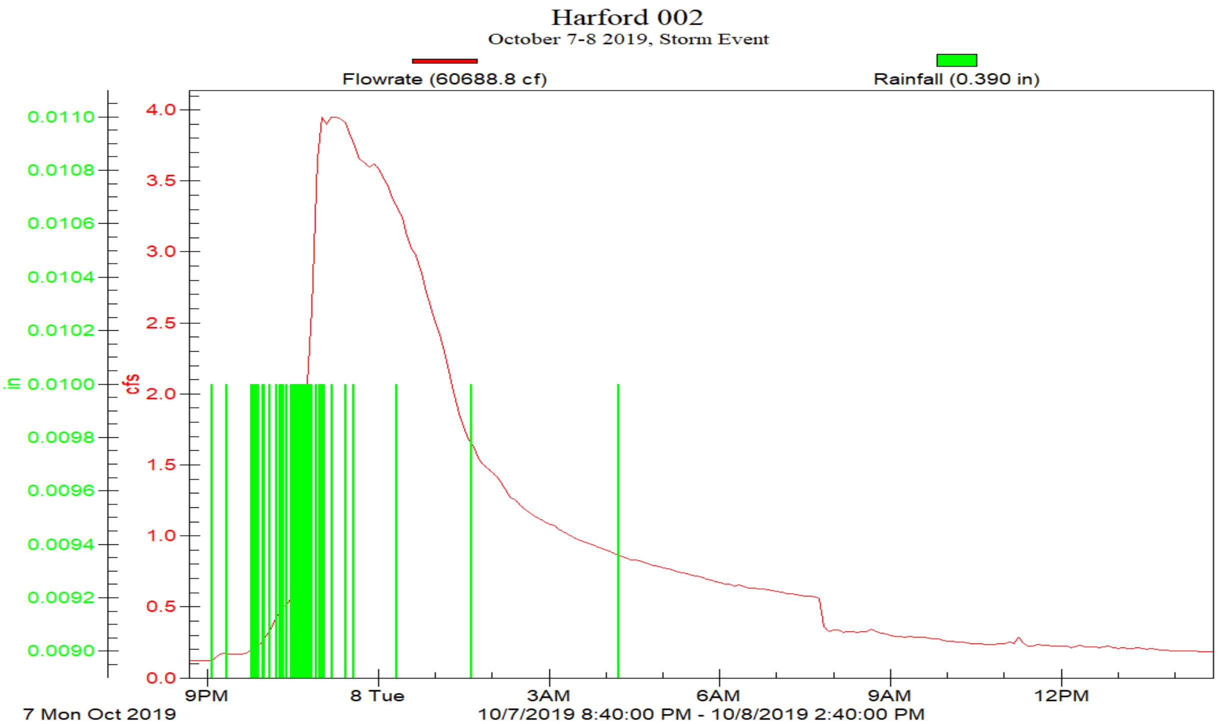

Figure A-1. Hydrograph at Station WC002 for October 7-8, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

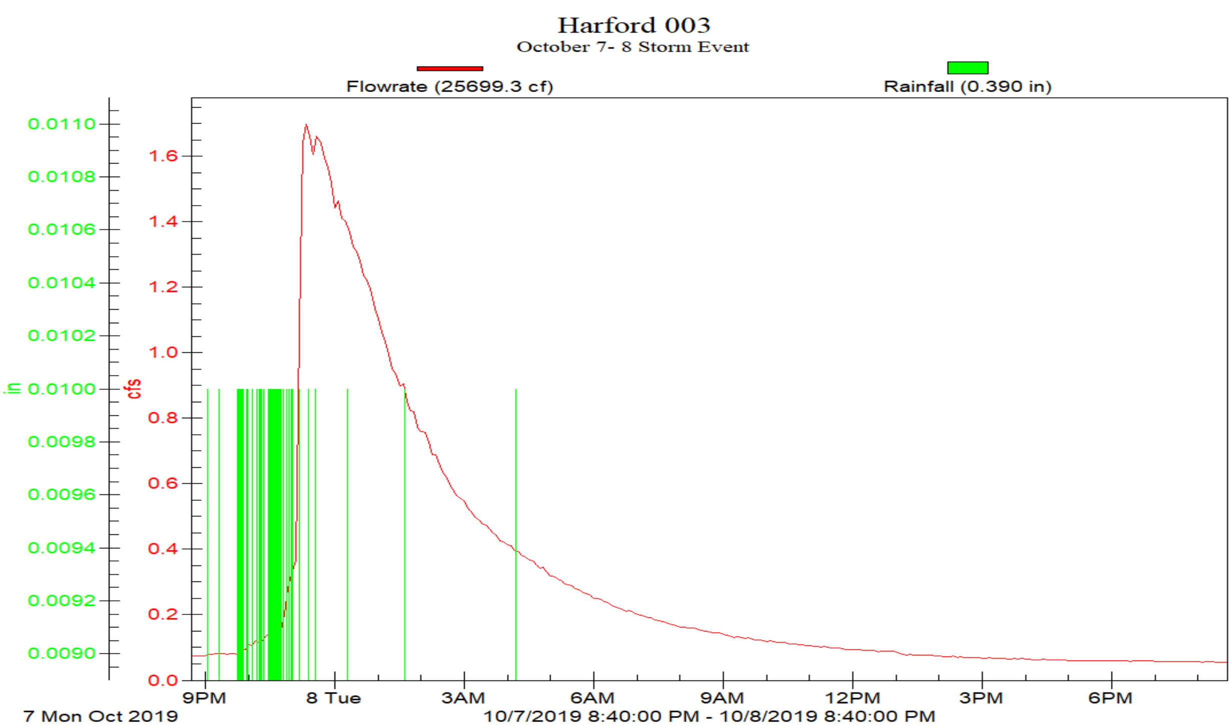

Figure A-2. Hydrograph at Station WC003 for October 7-8, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

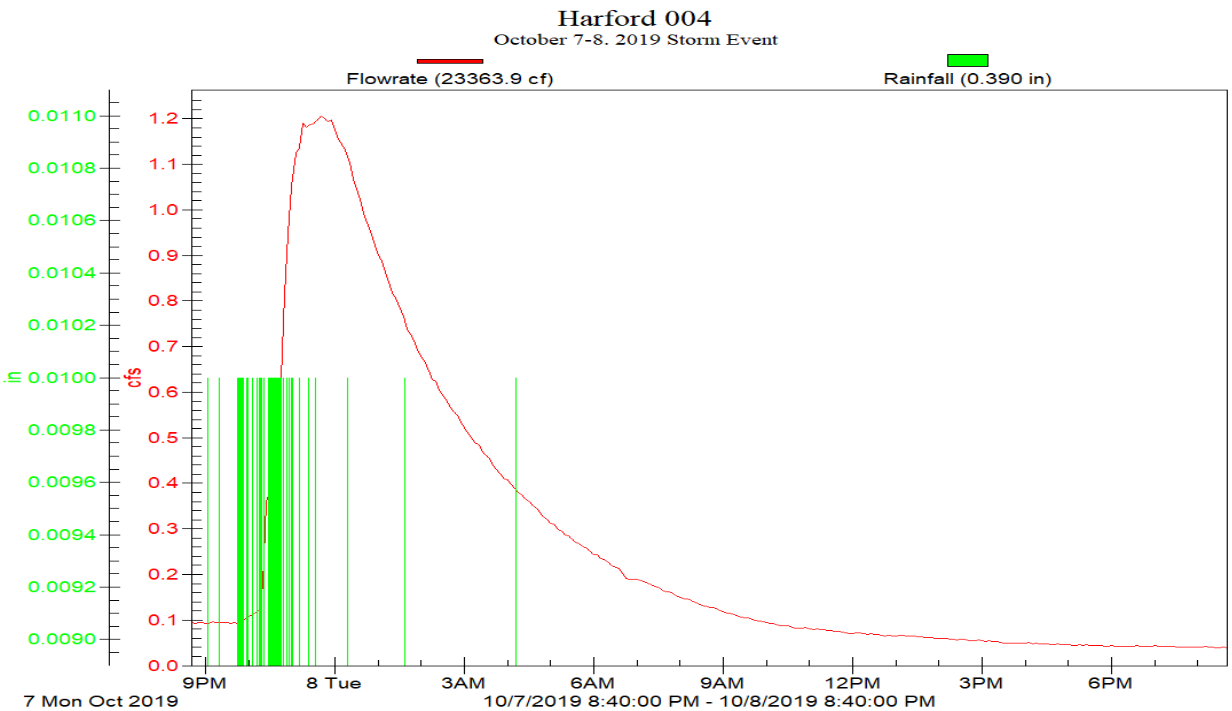

Figure A-3. Hydrograph at Station WC004 for October 7-8, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	7-8-Oct-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	<1	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.4	0.8	0.8
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	51	68	43
Copper	0.005	0.010	0.015
Lead	<0.001	0.002	0.002
Zinc	0.040	0.065	0.068
Ammonia Nitrogen	0.42	<0.30	<0.30
Kjeldahl Nitrogen (Total)	1.4	1.6	1.6
Total Phosphorus	0.13	0.19	0.13
Hardness	173	160	112
Chloride	107	93.0	72.1
pH	7.26	7.30	7.15

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	7-8-Oct-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	<1	<1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.8	0.5	0.4
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	64	21	17
Copper	0.009	0.004	0.007
Lead	0.002	<0.001	<0.001
Zinc	0.051	0.020	0.035
Ammonia Nitrogen	<0.30	<0.30	<0.30
Kjeldahl Nitrogen (Total)	1.7	1.0	1.1
Total Phosphorus	0.21	0.07	0.05
Hardness	112	100	48.0
Chloride	77.1	62.6	29.1
pH	7.36	7.39	7.26

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**7-8-Oct-2019**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	<1	<1	<1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.5	0.3	0.3
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	9	5	3
Copper	0.004	0.003	0.006
Lead	<0.001	<0.001	<0.001
Zinc	0.021	0.017	0.031
Ammonia Nitrogen	<0.30	<0.30	<0.30
Kjeldahl Nitrogen (Total)	0.9	0.8	0.9
Total Phosphorus	0.06	<0.05	<0.05
Hardness	72.0	97.0	64.0
Chloride	52.2	76.6	43.7
pH	7.36	7.42	7.29

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
October 8, 2019 (Falling)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	>2420	1050	>2420
Temp (C)	16.5	16.7	16.7
DO (mg/L)	8.94	8.87	7.68
pH	7.10	7.29	7.17
Sp. Cond. (mS/cm)	0.357	0.406	0.292

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.39	0.39	0.39
Duration (hrs.)	18	24	24
Intensity (in./hr.)	0.022	0.016	0.016
Discharge (cf.)	60,688	25,699	23,363

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

OCTOBER 9, 2019

INTRODUCTION

Versar field staff traveled to the site on October 9 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 5:34 a.m. the morning of Wednesday, October 9. At a local rain gauge station, Bel Air South, 0.18 inches of rain was recorded for the duration of the storm.

On the morning of October 10, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on October 10 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on October 10. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on October 10.

The following issue occurred during the October 9, 2019 storm event:

The onsite rain gauge failed to record rainfall and the USGS rain gauge was offline; therefore, the field staff used rainfall data from a local Weather Underground rain gauge (KMDBELAI60).

RESULTS

Hydrographs for the October 9 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the October 9 event are shown in Table A-5.

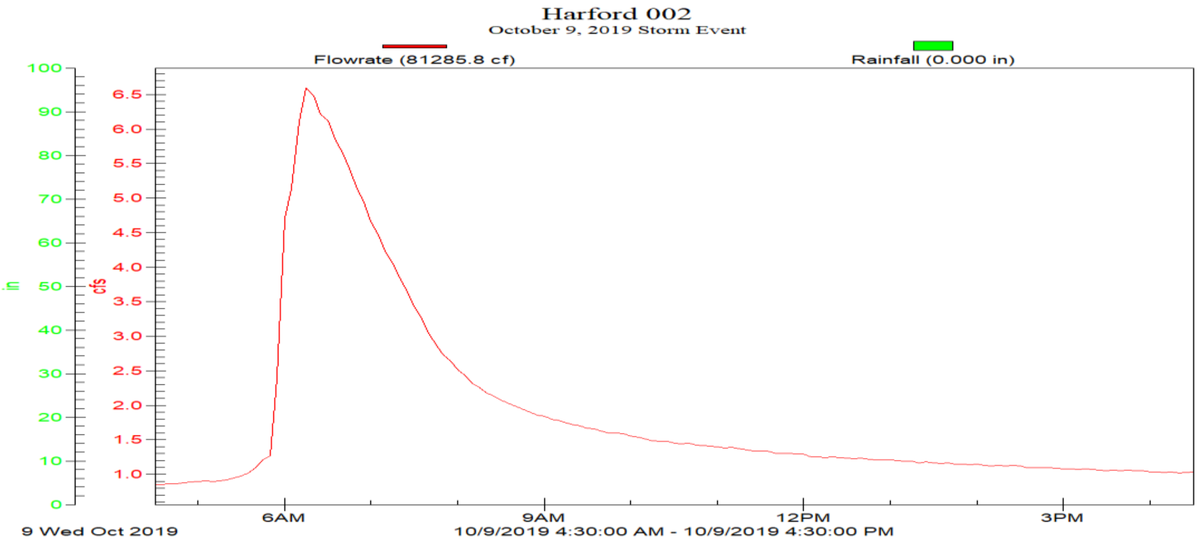

Figure A-1. Hydrograph at Station WC002 for October 9, 2019 storm. Rainfall data source: Weather Underground, Bel Air South

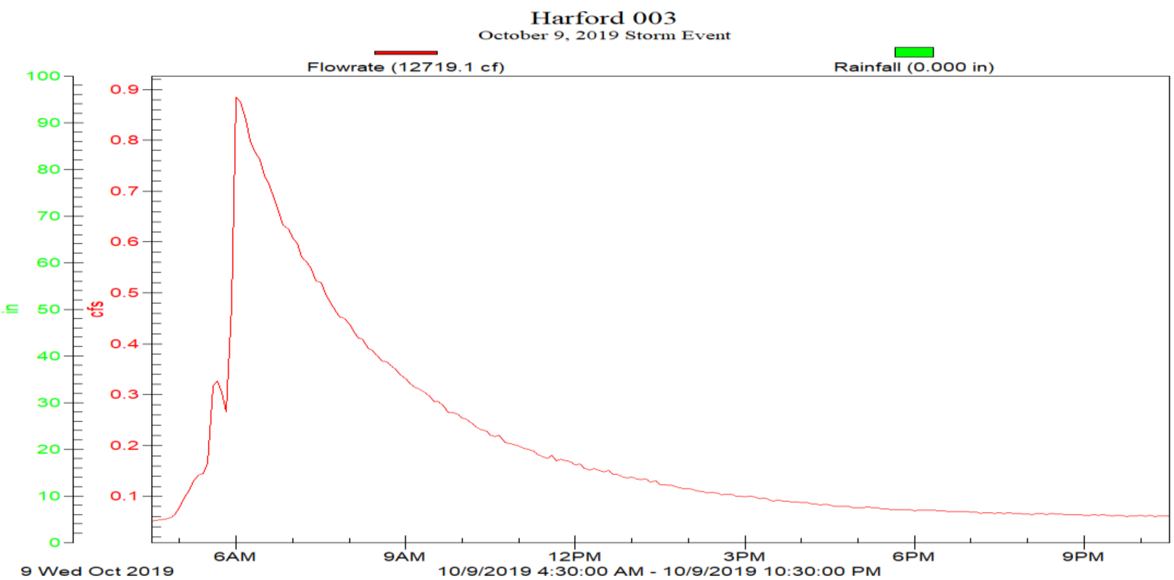

Figure A-2. Hydrograph at Station WC003 for October 9, 2019 storm. Rainfall data source: Weather Underground, Bel Air South

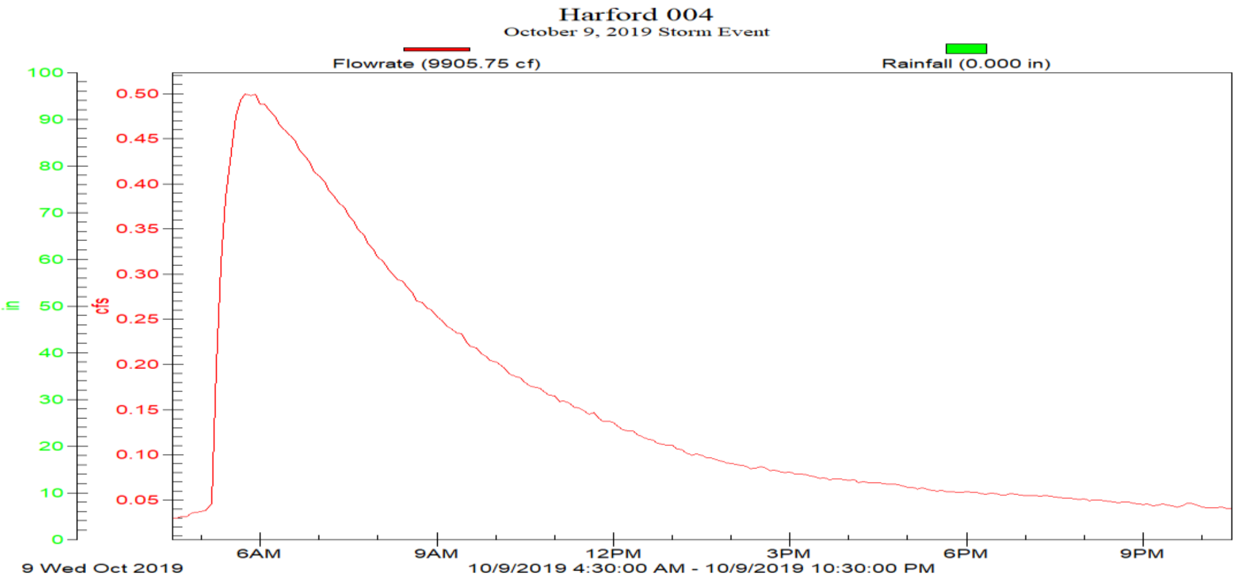

Figure A-3. Hydrograph at Station WC004 for October 9, 2019 storm. Rainfall data source: Weather Underground, Bel Air South.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	10-Oct-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.4	0.8
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	4	6	8
Copper	<0.002	<0.002	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.026	0.013	0.025
Ammonia Nitrogen	0.45	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.6	0.7	0.8
Total Phosphorus	0.02	0.03	0.009
Hardness	133	128	112
Chloride	80.6	96.8	91.3
pH	7.24	7.44	7.18
NT = not tested			

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	10-Oct-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	<1	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.5	0.3	0.2
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	9	4	3
Copper	0.004	0.002	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.029	<0.01	0.039
Ammonia Nitrogen	0.08	0.05	<0.3
Kjeldahl Nitrogen (Total)	0.8	0.7	0.7
Total Phosphorus	0.05	0.02	0.02
Hardness	59	91	44
Chloride	58.2	70.3	28.6
pH	7.29	7.51	7.26
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	10-Oct-2019 Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	<1	<1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.4	0.2	0.3
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	2	<2	<2
Copper	<0.002	<0.002	0.002
Lead	<0.001	<0.001	<0.001
Zinc	<0.01	<0.01	<0.01
Ammonia Nitrogen	0.05	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.6	0.6	0.8
Total Phosphorus	0.02	0.009	0.01
Hardness	80	98	61
Chloride	58.7	79.6	39.9
pH	7.30	7.55	7.26

NT= not tested

Table A-4. Analytical Results – Wheel Creek Grab Sampling

Constituent	Station WC002	Station WC003	Station WC004
October 10, 2019 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	488	248	365
Temp (C)	14.7	14.7	16.1
DO (mg/L)	9.17	9.46	7.66
pH	7.00	7.27	6.96
Sp. Cond. (mS/cm)	0.411	0.441	0.565

Table A-5. Rainfall and flow statistics

Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.18	0.18	0.18
Duration (hrs.)	12	18	18
Intensity (in./hr.)	0.015	0.010	0.010
Discharge (cf.)	81,285	12,719	9,905

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

OCTOBER 22-23, 2019

INTRODUCTION

Versar field staff traveled to the site on October 22 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 2:23 p.m. the afternoon of Tuesday, October 22. At the Wheel Creek Rain Gauge Station, 0.72 inches of rain was recorded for the duration of the storm.

On the evening of October 22, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on October 23 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on October 23. Composite samples, including TPH samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on October 23.

RESULTS

Hydrographs for the October 22-23 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the October 22-23 storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the event are shown in Table A-5.

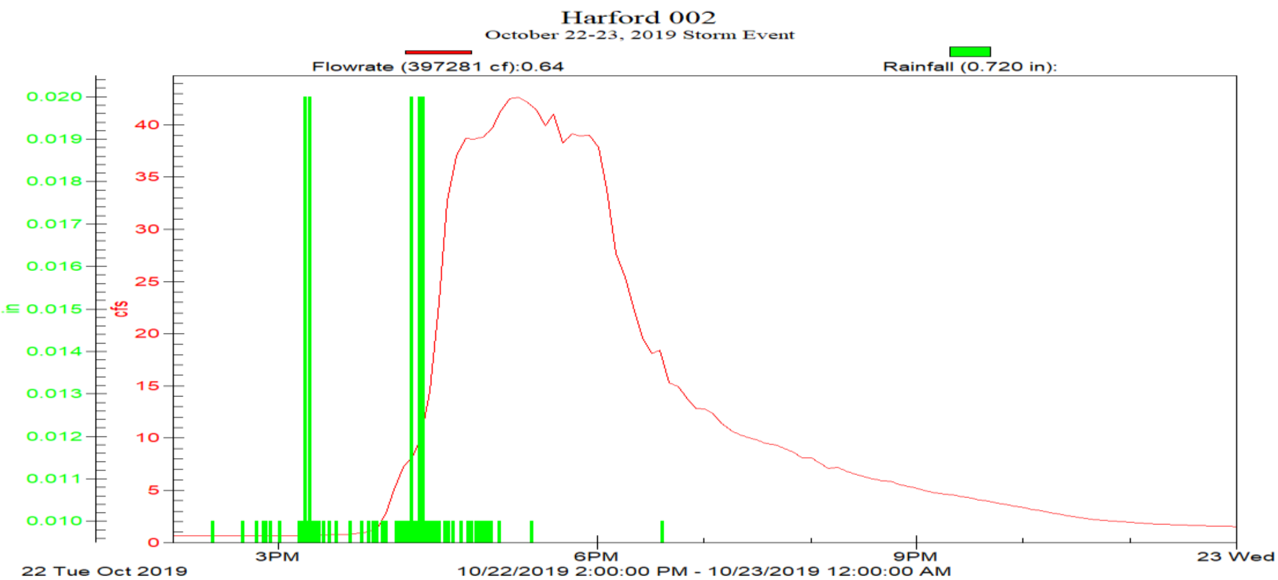

Figure A-1. Hydrograph at Station WC002 for October 22-23, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

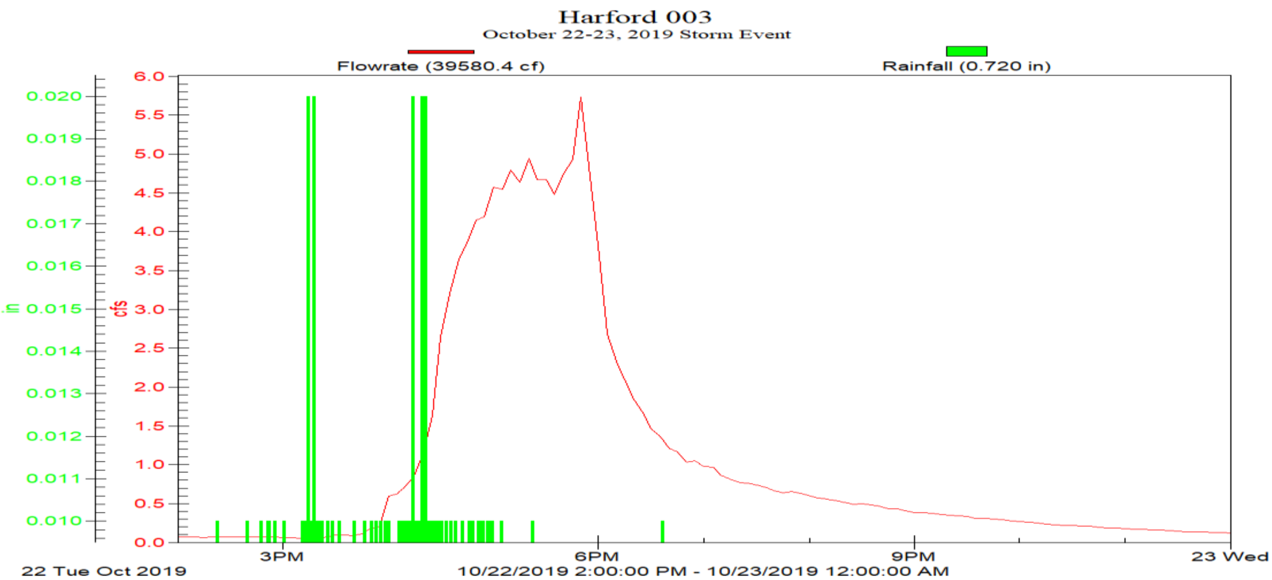

Figure A-2. Hydrograph at Station WC003 for October 22-23, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

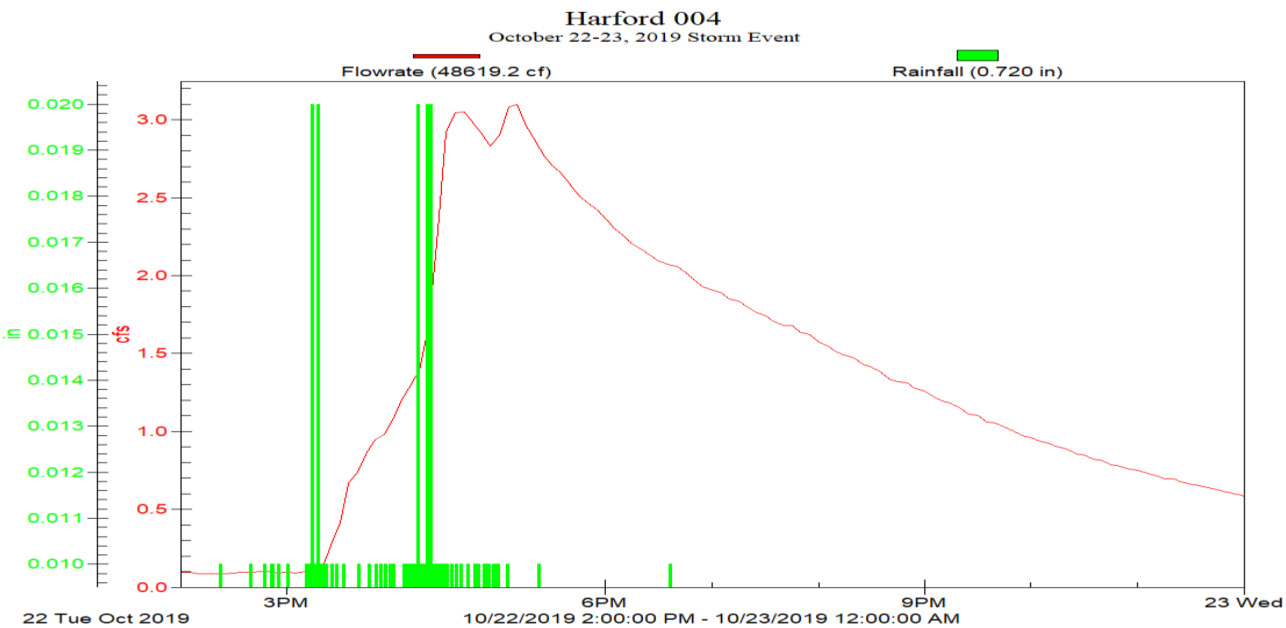

Figure A-3. Hydrograph at Station WC004 for October 22-23, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	22-23-Oct-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	3	3
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.4	0.7
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	<2	34	26
Copper	<0.002	0.01	0.01
Lead	<0.001	0.001	0.001
Zinc	0.011	0.099	0.041
Ammonia Nitrogen	0.49	<0.3	0.06
Kjeldahl Nitrogen (Total)	0.5	1.0	1.0
Total Phosphorus	0.009	0.09	0.07
Hardness	131	108	68
Chloride	93.4	64.7	63.7
pH	7.46	7.05	7.09
NT = not tested			

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	22-23 Oct-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	3	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.6	0.3	0.2
Orthophosphate Phosphorus	<0.05	0.02	<0.05
Solids (Suspended)	28	37	9
Copper	0.007	0.009	0.005
Lead	0.001	0.002	<0.001
Zinc	0.032	0.039	0.019
Ammonia Nitrogen	0.17	<0.3	<0.3
Kjeldahl Nitrogen (Total)	1.0	1.0	0.7
Total Phosphorus	0.1	0.12	0.03
Hardness	92	52	20
Chloride	56.4	22.7	9.18
pH	7.41	7.23	7.50
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	22-23-Oct-2019 Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	2	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.3	0.3	0.2
Orthophosphate Phosphorus	0.02	<0.05	<0.05
Solids (Suspended)	12	9	2
Copper	0.006	0.005	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.03	0.014	0.014
Ammonia Nitrogen	0.06	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.8	0.8	0.6
Total Phosphorus	0.08	0.05	0.01
Hardness	44	42	26
Chloride	14.4	22.3	14.9
pH	7.44	7.17	6.82
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling

Constituent	Station WC002	Station WC003	Station WC004
October 23, 2019 (Rising)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	548	>2420	>2420
Temp (C)	15	15.1	15
DO (mg/L)	9.18	9.58	8.77
pH	7.27	7.27	6.86
Sp. Cond. (mS/cm)	0.422	0.358	0.554

Table A-5. Rainfall and flow statistics

Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.72	0.72	0.72
Duration (hrs.)	10	10	10
Intensity (in./hr.)	0.072	0.072	0.072
Discharge (cf.)	401,036	39,737	50,644

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

DECEMBER 9-10, 2019

INTRODUCTION

Versar field staff traveled to the site on December 9 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 10:30 a.m. the morning of Monday, December 9. At the Wheel Creek Rain Gauge Station, 0.87 inches of rain was recorded for the duration of the storm.

On the morning of December 9, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on December 10 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on December 10. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on December 10.

RESULTS

Hydrographs for the December 9-10 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the December 9-10 event are shown in Table A-5.

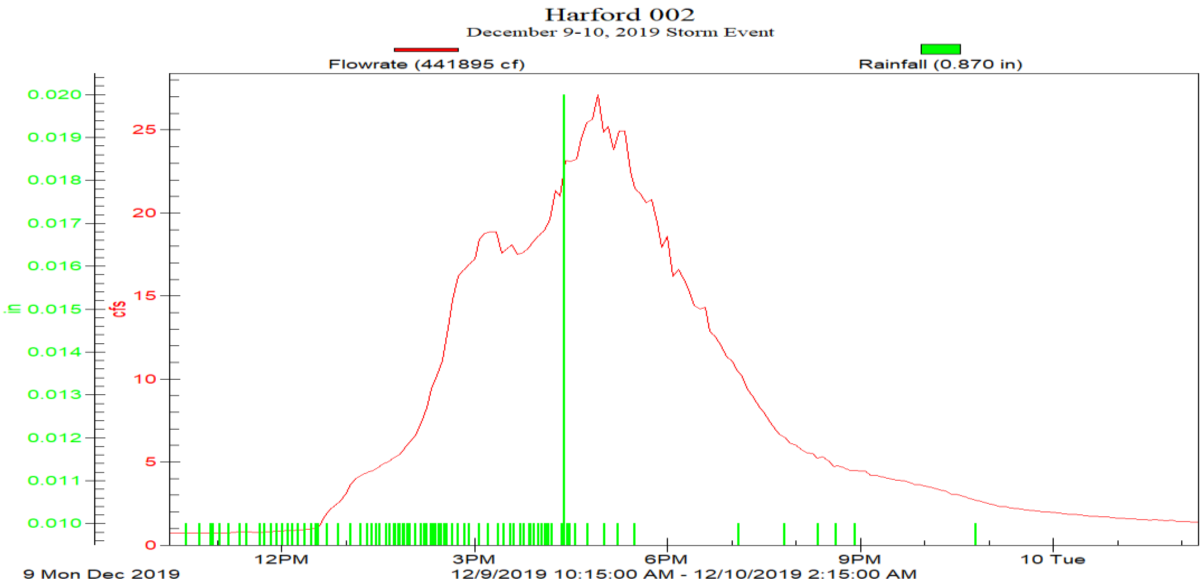

Figure A-1. Hydrograph at Station WC002 for December 9-10, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

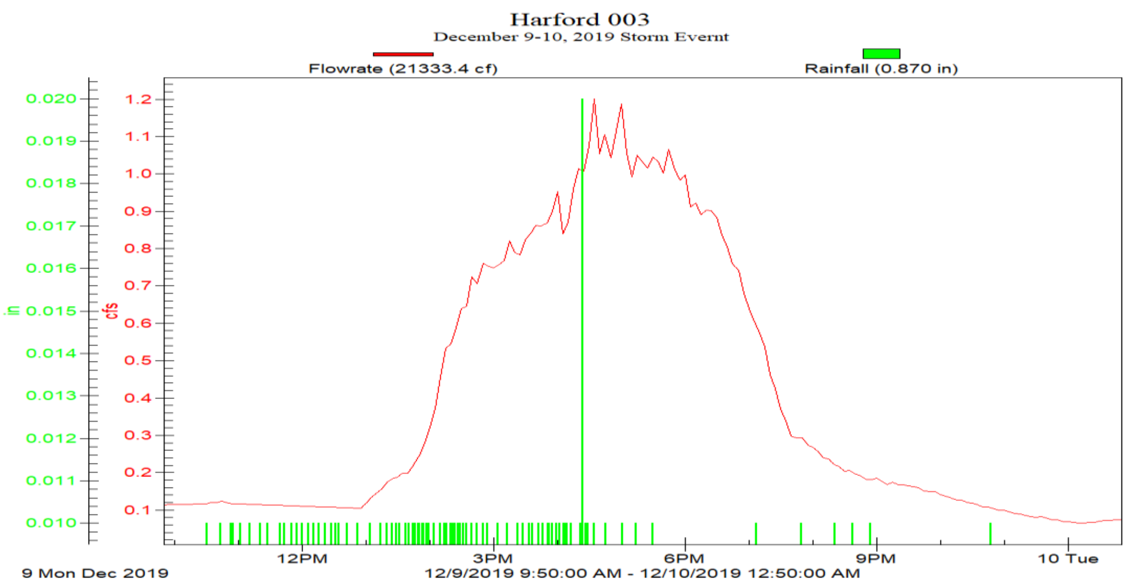

Figure A-2. Hydrograph at Station WC003 for December 9-10, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

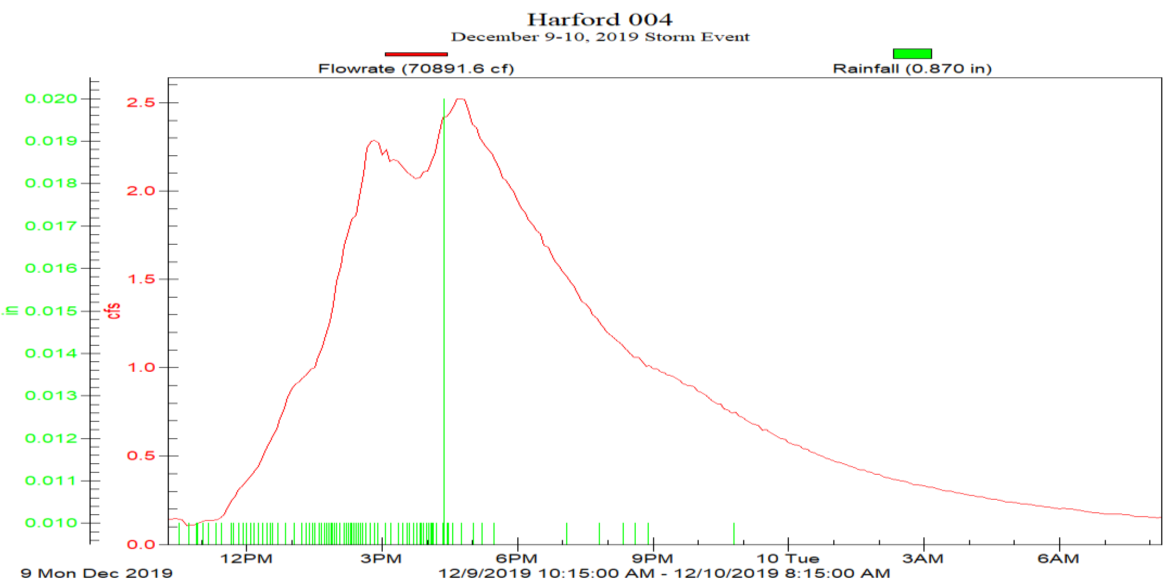

Figure A-3. Hydrograph at Station WC004 for December 9-10, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	9-10-Dec-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	5	4	4
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.6	0.3	0.3
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	18	16	13
Copper	0.005	0.006	0.008
Lead	<0.001	<0.001	0.001
Zinc	0.042	0.037	0.052
Ammonia Nitrogen	0.05	0.13	0.14
Kjeldahl Nitrogen (Total)	0.6	0.7	0.9
Total Phosphorus	0.12	0.04	0.07
Hardness	80	52	32
Chloride	57.3	37.8	26.1
pH	7.69	7.19	7.14

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	9-10-Dec-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	3	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.3	0.3	0.2
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	13	8	3
Copper	0.006	0.005	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.029	0.032	0.044
Ammonia Nitrogen	0.05	<0.3	0.14
Kjeldahl Nitrogen (Total)	0.6	0.5	0.5
Total Phosphorus	0.1	0.07	0.03
Hardness	32	38	17
Chloride	<25	23.3	9.43
pH	7.43	7.06	7.18

NT = not tested

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	9-10-Dec-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	2	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.6	0.3	0.4
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	5	4	4
Copper	0.004	0.005	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.029	0.026	0.036
Ammonia Nitrogen	<0.3	0.1	0.32
Kjeldahl Nitrogen (Total)	0.6	0.5	0.5
Total Phosphorus	0.06	0.05	0.02
Hardness	50	46	34
Chloride	29.6	31.6	24.2
pH	7.07	7.03	6.96
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	Station WC002	Station WC003	Station WC004
December 10, 2019 (Rising)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	35	90.5	119
Temp (C)	7.6	6.8	9
DO (mg/L)	11.4	10.47	9.51
pH	7.39	7.04	7.06
Sp. Cond. (mS/cm)	0.498	0.492	0.654

Table A-5. Rainfall and flow statistics			
Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.87	0.87	0.87
Duration (hrs.)	18	12	22
Intensity (in./hr.)	0.048	0.073	0.040
Discharge (cf.)	452,448	20,121	70,952

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

FEBRUARY 5-6, 2020

INTRODUCTION

Versar field staff traveled to the site on February 5 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 11:02 p.m. the evening of Wednesday, February 5. At the Wheel Creek Rain Gauge Station, 0.17 inches of rain was recorded for the duration of the storm.

On the morning of February 6, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on February 6 to composite automated samples and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on February 6. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on February 6.

The following issue occurred during the storm event:

At Station WC002, the ISCO flowmeter bubbler became detached from the sensor during the peak and falling limbs. The hydrograph from Station WC003 was used by field staff to composite the storm; as a result, it was determined from later analyses that the target composite bottles were slightly skewed to later times at Station WC002. Also, follow-on rain after composite from a separate storm caused elevated flows, as seen in Figures A-2 and A-3.

RESULTS

Hydrographs for the February 5-6 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the February 5-6 event are shown in Table A-5.

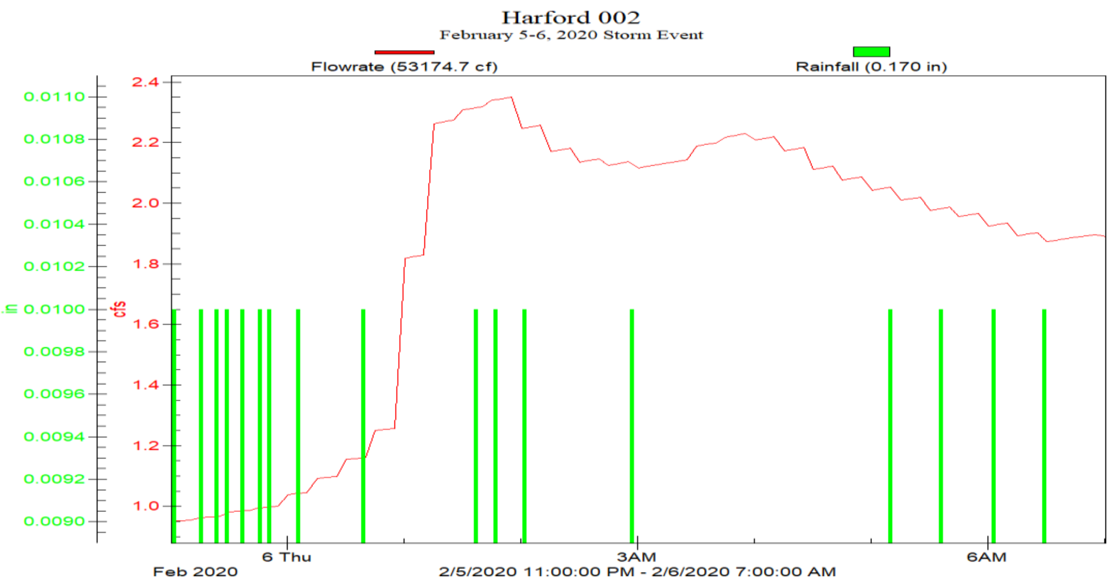

Figure A-1. Hydrograph at Station WC002 for February 5-6, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

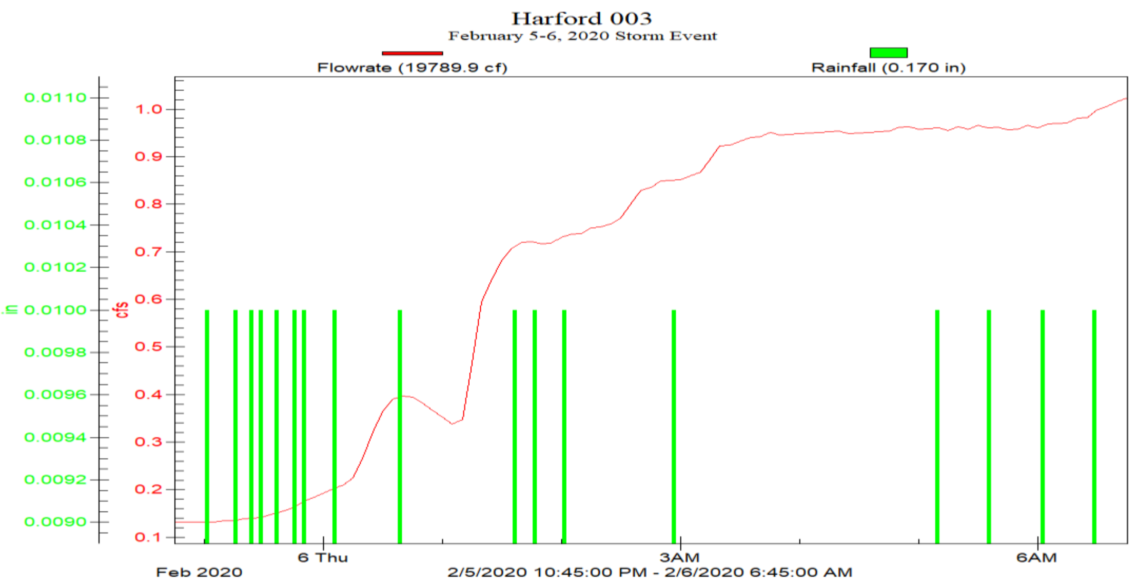

Figure A-2. Hydrograph at Station WC003 for February 5-6, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

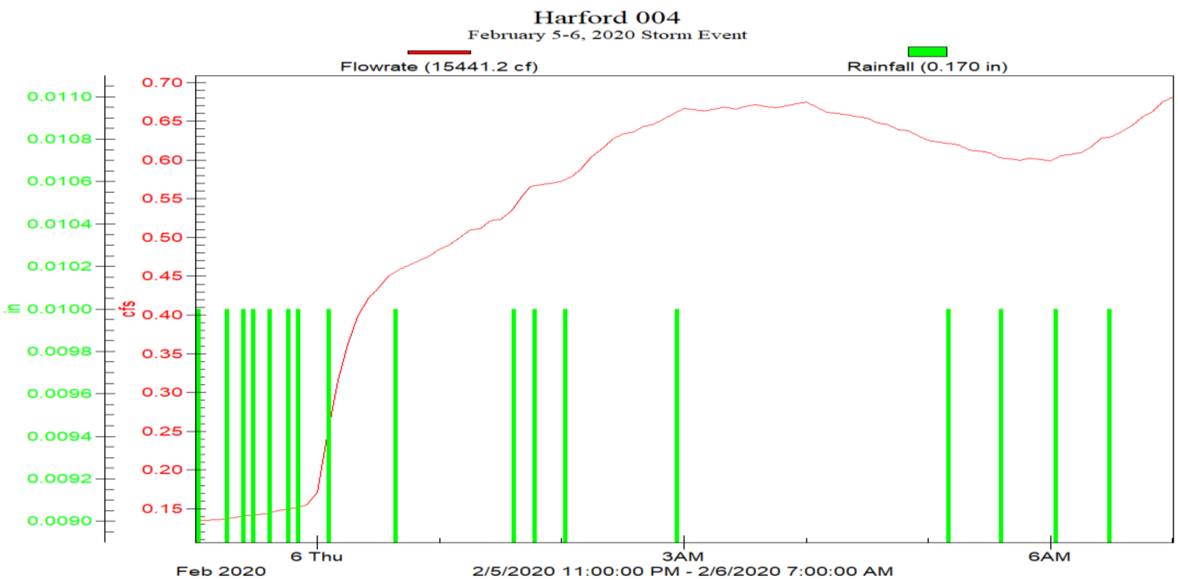

Figure A-3. Hydrograph at Station WC004 for February 5-6, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	**5-6-Feb-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	<1	<1	3
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.3	1.1	0.9
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	<2	4	6
Copper	<0.002	0.002	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.016	0.023	0.035
Ammonia Nitrogen	0.3	<0.3	0.06
Kjeldahl Nitrogen (Total)	0.5	0.5	0.8
Total Phosphorus	0.02	0.009	0.03
Hardness	122	154	116
Chloride	151	160	231
pH	7.25	8.30	7.06
NT = not tested			

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**5-6-Feb-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	1	3
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.9	0.5
Orthophosphate Phosphorus	0.01	<0.05	<0.05
Solids (Suspended)	<2	2	3
Copper	0.002	0.002	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.013	0.013	0.038
Ammonia Nitrogen	0.12	<0.3	0.05
Kjeldahl Nitrogen (Total)	0.5	0.5	0.8
Total Phosphorus	0.01	0.02	0.03
Hardness	104	142	84
Chloride	119	177	192
pH	7.30	7.60	7.20
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**5-6-Feb-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	1	<1	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1	0.8	0.6
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	<2	2	3
Copper	0.002	0.002	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.013	0.013	0.037
Ammonia Nitrogen	0.06	0.06	0.06
Kjeldahl Nitrogen (Total)	0.5	0.5	0.7
Total Phosphorus	0.02	0.01	0.03
Hardness	102	128	84
Chloride	128	171	173
pH	7.33	7.55	7.22
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
February 6, 2020 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	108	137	435
Temp (C)	6.9	6.7	7.1
DO (mg/L)	11.77	11.51	11.30
pH	7.18	7.80	7.35
Sp. Cond. (mS/cm)	0.515	0.651	0.517

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.17	0.17	0.17
Duration (hrs.)	8	8	8
Intensity (in./hr.)	0.021	0.021	0.021
Discharge (cf.)	53,174	22,832	15,441

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

FEBRUARY 12-13, 2020

INTRODUCTION

Versar field staff traveled to the site on February 12 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 8:00 p.m. the evening of Wednesday, February 12. At a local Rain Gauge Station, 0.24 inches of rain was recorded for the duration of the storm.

On the morning of February 13, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on February 13 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on February 13. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on February 13.

The following issue occurred during the storm event:

The stream level at Station WC003 was elevated during the composite so the field staff came back to collect a manual grab sample to represent the falling limb after compositing the other stations at 1:30 p.m.

RESULTS

Hydrographs for the February 12-13 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the February 12-13 event are shown in Table A-5.

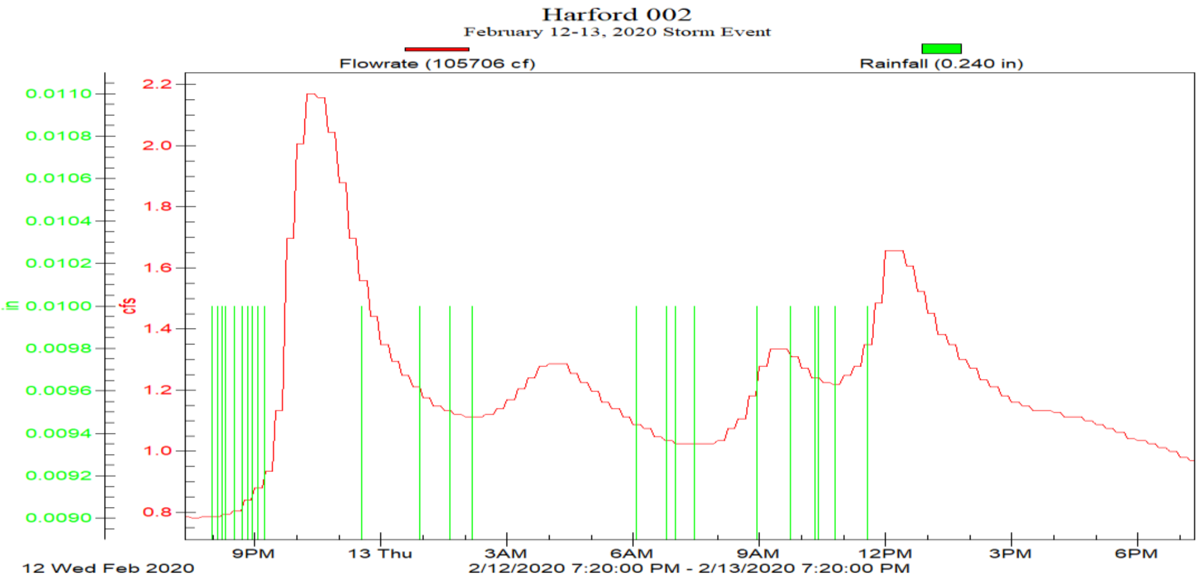

Figure A-1. Hydrograph at Station WC002 for February 12-13, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

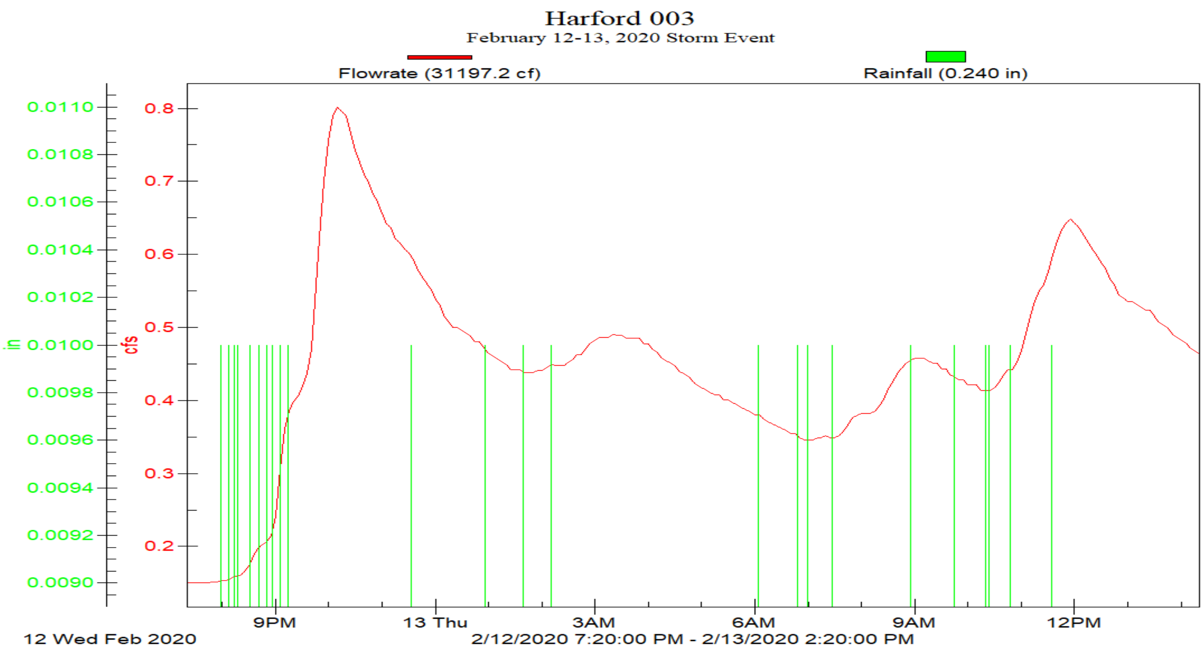

Figure A-2. Hydrograph at Station WC003 for February 12-13, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

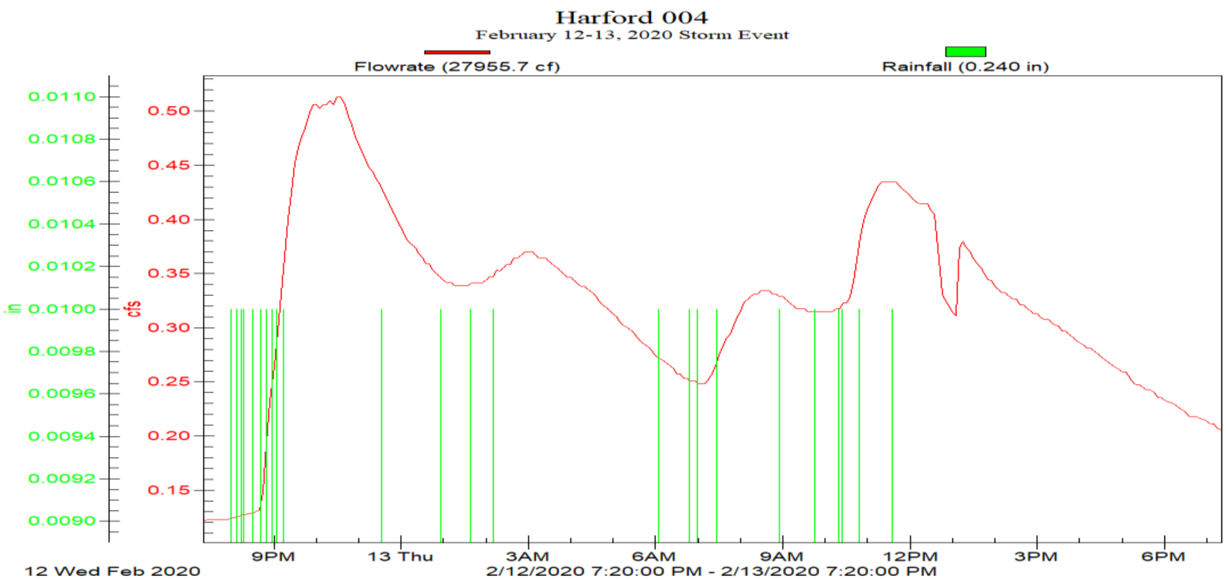

Figure A-3. Hydrograph at Station WC004 for February 20-21, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	12-13-Feb-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.5	0.9	1.3
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	9	3	5
Copper	0.002	0.002	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.016	0.011	0.044
Ammonia Nitrogen	0.28	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.4	0.4	0.5
Total Phosphorus	0.02	0.01	0.03
Hardness	112	112	109
Chloride	103	110	124
pH	6.92	7.17	7.00

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	12-13-Feb-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	1	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.7	0.5
Orthophosphate Phosphorus	<0.05	<0.05	0.02
Solids (Suspended)	3	<2	137
Copper	0.002	<0.002	0.009
Lead	<0.001	<0.001	0.009
Zinc	0.011	0.012	0.057
Ammonia Nitrogen	0.06	<0.3	0.06
Kjeldahl Nitrogen (Total)	0.5	0.4	0.6
Total Phosphorus	0.02	0.009	0.06
Hardness	93	88	54
Chloride	85.2	90	58.9
pH	7.04	7.27	7.24

NT = not tested

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	12-13-Feb-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	2	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.7	0.8
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	<2	4	3
Copper	0.002	0.002	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.011	0.015	0.029
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.5	0.4	0.5
Total Phosphorus	0.01	0.02	0.02
Hardness	98	79	60
Chloride	80.3	81.3	77.6
pH	7.06	7.19	7.10
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	Station WC002	Station WC003	Station WC004
February 13, 2020 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	43.2	649	308
Temp (C)	7.7	7.7	7.9
DO (mg/L)	11.41	11.72	10.84
pH	6.87	7.16	7.08
Sp. Cond. (mS/cm)	0.369	0.365	0.279

Table A-5. Rainfall and flow statistics			
Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.24	0.24	0.24
Duration (hrs.)	12	19	24
Intensity (in./hr.)	0.020	0.013	0.010
Discharge (cf.)	54,268	31,197	27,955

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

APRIL 12-14, 2020

INTRODUCTION

Versar field staff traveled to the site on April 12 to deploy siphon samplers and program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 8:58 p.m. the evening of Sunday, April 12. At the Wheel Creek Rain Gauge Station, 3.65 inches of rain was recorded for the duration of the storm.

On the morning of April 14, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on April 14 to composite automated samples. Siphon samples were not deployed for this event per County request. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on April 14.

The following issue occurred during the storm event:

The ISCO bubbler tubing became detached at stations WC002 and WC003 due to debris. Versar field staff used the hydrograph from Station WC004 to determine discrete sample volumes to use for the composite samples at both stations.

RESULTS

Hydrographs for the April 12-14 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the April 12-14 event are shown in Table A-5.

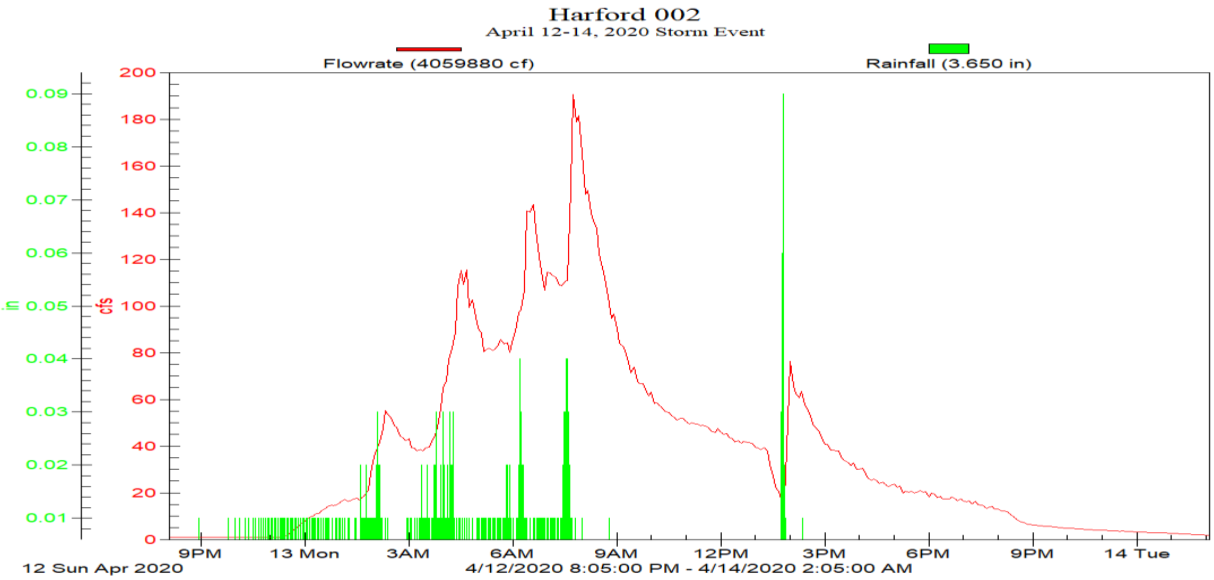

Figure A-1. Hydrograph at Station WC002 for April 12-14, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

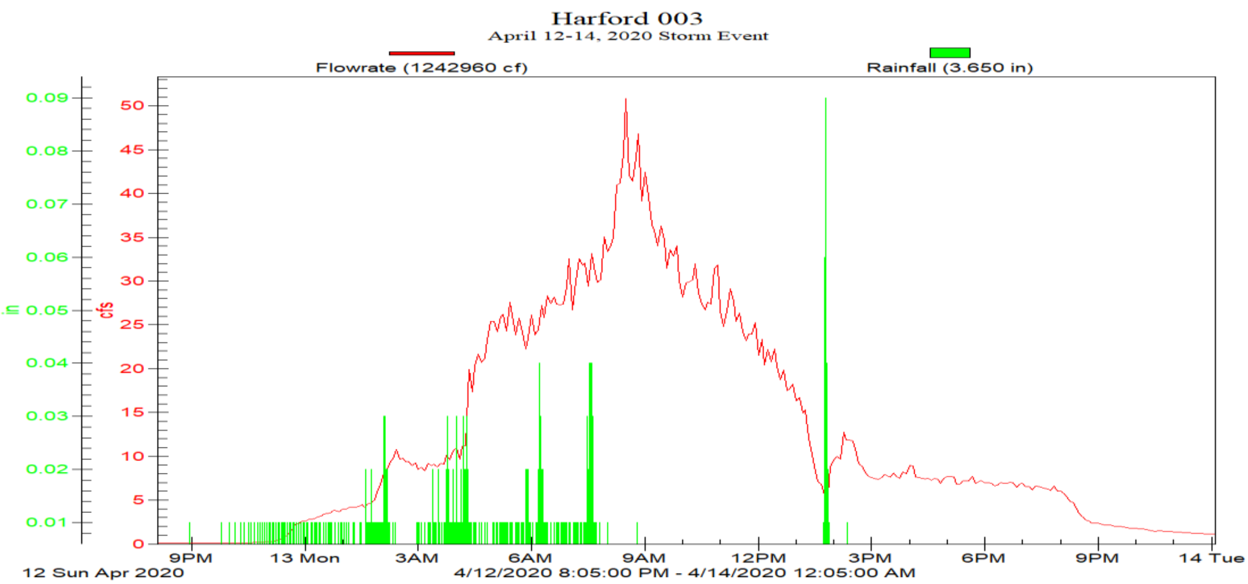

Figure A-2. Hydrograph at Station WC003 for April 12-14, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

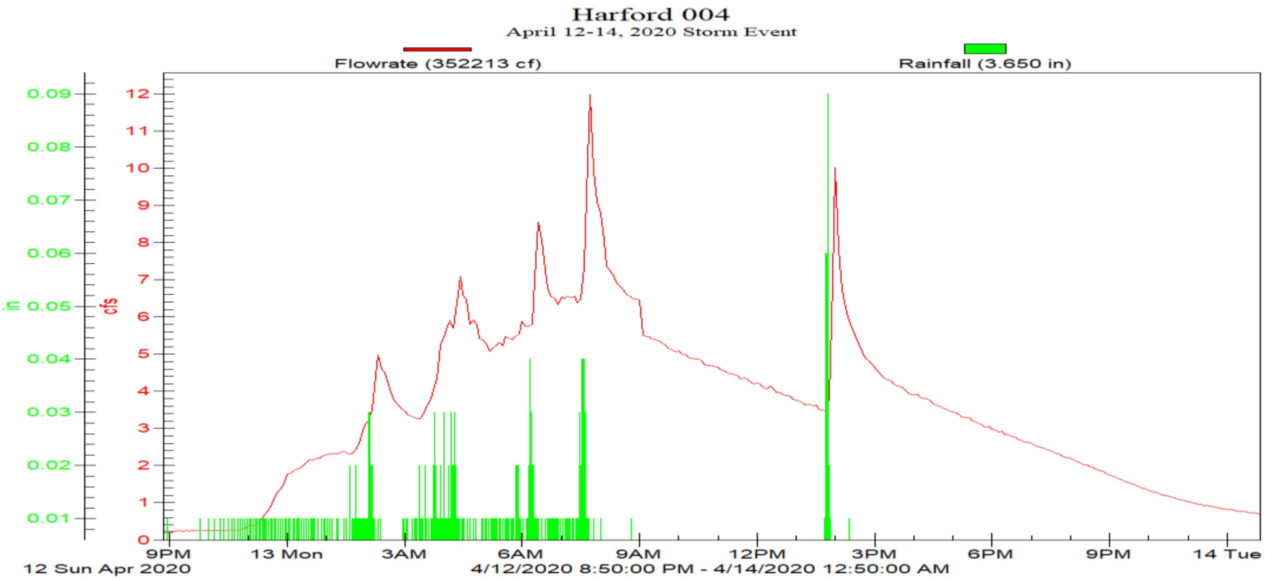

Figure A-3. Hydrograph at Station WC004 for April 12-14, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	**12-14-April-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	5	3	3
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.9	0.6	0.6
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	9	53	23
Copper	0.009	0.01	0.01
Lead	0.002	0.002	0.001
Zinc	0.043	0.038	0.042
Ammonia Nitrogen	0.24	0.12	0.22
Kjeldahl Nitrogen (Total)	1.2	1.1	1.2
Total Phosphorus	0.16	0.12	0.14
Hardness	93	102	58
Chloride	65.7	86.5	51.3
pH	6.77	7.01	7.08
NT = not tested			

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**12-14-April-2020**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	5	4	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.4	0.3	0.2
Orthophosphate Phosphorus	0.06	0.02	0.02
Solids (Suspended)	81	69	17
Copper	0.02	0.015	0.008
Lead	0.004	0.002	0.001
Zinc	0.081	0.041	0.024
Ammonia Nitrogen	0.22	0.11	0.12
Kjeldahl Nitrogen (Total)	1.8	1.1	0.8
Total Phosphorus	0.42	0.18	0.07
Hardness	24	25	13
Chloride	9.27	11.5	5.66
pH	7.34	7.44	7.19
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	12-14-April-2020 Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	2	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.3	0.3	0.2
Orthophosphate Phosphorus	0.06	0.02	0.01
Solids (Suspended)	30	28	8
Copper	0.01	0.01	0.005
Lead	0.002	0.002	<0.001
Zinc	0.026	0.023	0.021
Ammonia Nitrogen	0.15	0.34	0.14
Kjeldahl Nitrogen (Total)	1.0	0.8	0.8
Total Phosphorus	0.17	0.11	0.04
Hardness	23	24	18
Chloride	12.3	12.4	12
pH	7.23	7.28	6.91

NT = not tested

Table A-4. Analytical Results – Wheel Creek Grab Sampling

Constituent	Station WC002	Station WC003	Station WC004
April 14, 2020 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	1200	488	326
Temp (C)	12.3	10.8	12.8
DO (mg/L)	10.35	10.12	8.91
pH	6.93	7.04	6.87
Sp. Cond. (mS/cm)	0.335	0.307	0.335

Table A-5. Rainfall and flow statistics

Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	3.65	3.65	3.65
Duration (hrs.)	24	28	28
Intensity (in./hr.)	0.152	0.130	0.130
Discharge (cf.)	4,023,690	1,251,100	354,615

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JUNE 20-21, 2020

INTRODUCTION

Versar field staff traveled to the site on June 19 to program the ISCO automated samplers to sample the event. Rainfall initiated at approximately 1:17 p.m. the afternoon of Saturday, June 20. At the Wheel Creek Rain Gauge Station, 1.57 inches of rain was recorded for the duration of the storm.

Field staff traveled to the sites on June 22 to composite automated samples. Siphon samples were not deployed for this event per County request. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on June 22.

The following issue occurred during the storm event:

ISCO bubbler tubing became detached due to debris at the WC003 station. Versar field staff used the data at the WC002 station to determine discrete sample volumes to use for the composite. No flush samples were obtained due to the timing of the storm event. No siphon samplers were deployed for the event.

RESULTS

Hydrographs for the June 20-21 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the June 20-21 event are shown in Table A-5.

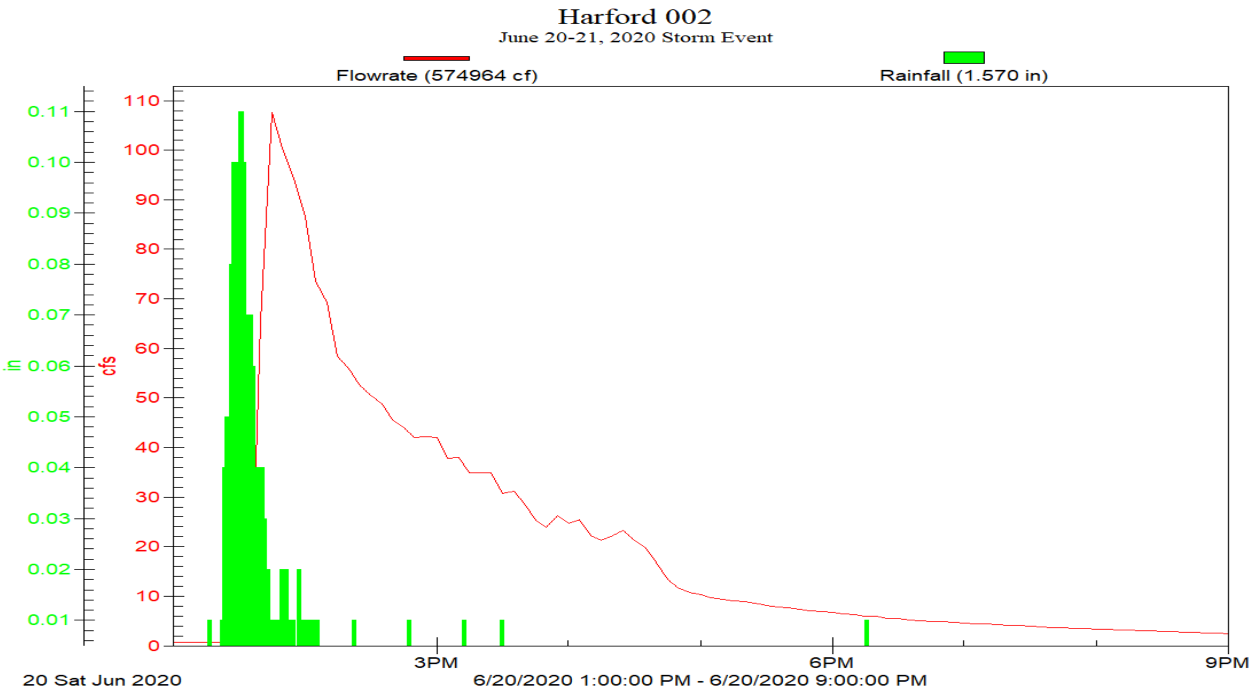

Figure A-1. Hydrograph at Station WC002 for June 20-21, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

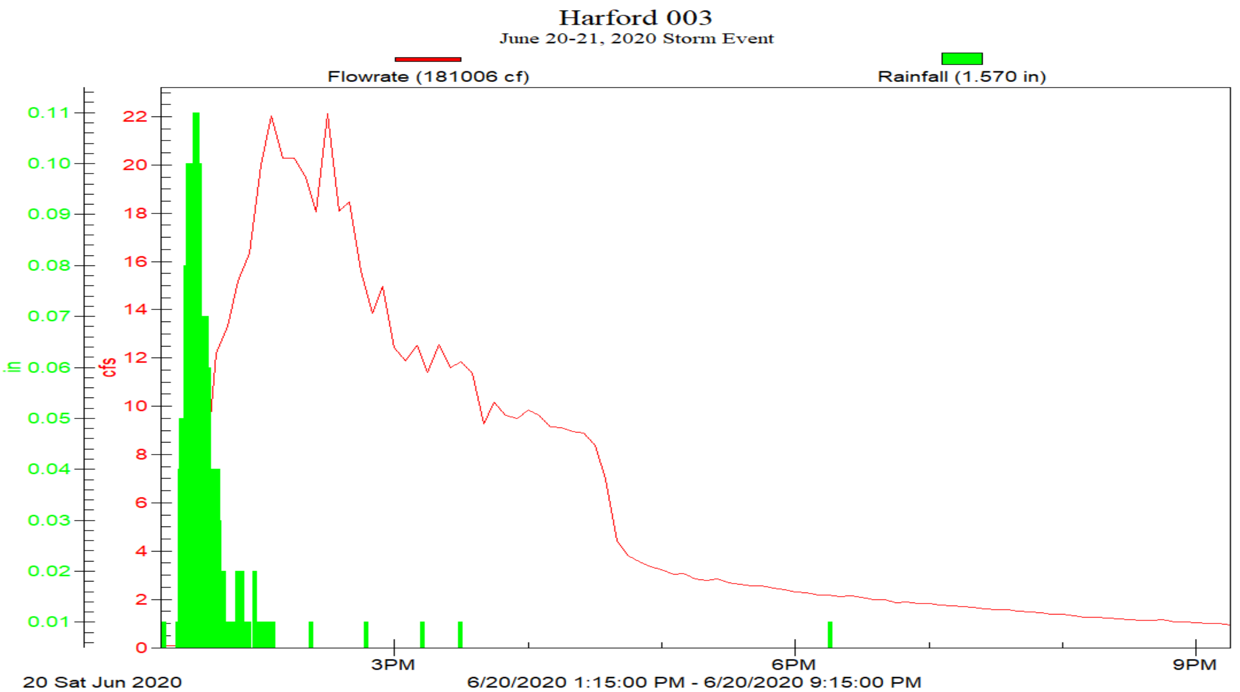

Figure A-2. Hydrograph at Station WC003 for June 20-21, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

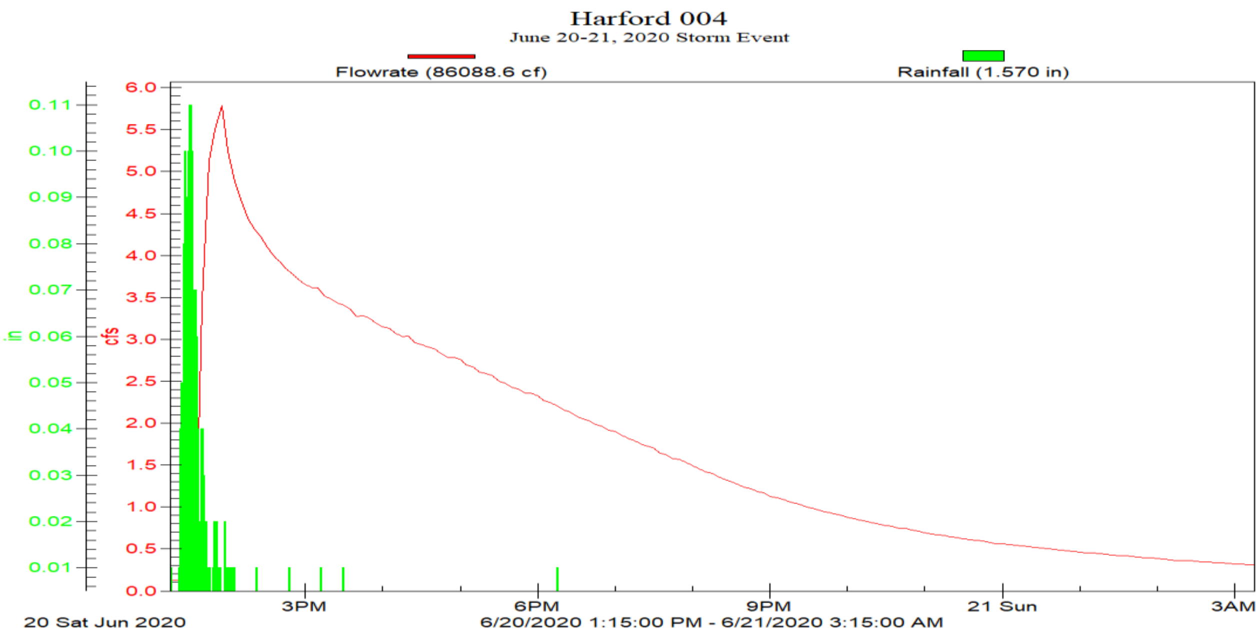

Figure A-3. Hydrograph at Station WC004 for June 20-21, 2020 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	20-21-June-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	2	<1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.7	2.1
Orthophosphate Phosphorus	0.02	0.01	<0.05
Solids (Suspended)	26	251	14
Copper	0.005	0.018	0.002
Lead	0.001	0.006	<0.001
Zinc	0.024	0.062	0.021
Ammonia Nitrogen	0.17	0.23	0.06
Kjeldahl Nitrogen (Total)	1.0	2.3	0.6
Total Phosphorus	0.13	0.4	0.02
Hardness	125	164	210
Chloride	79.7	113	177
pH	7.30	7.23	7.05
NT = not tested, N/A = not applicable			

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	20-21-June-2020		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	3	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.4	0.3	0.2
Orthophosphate Phosphorus	0.02	0.01	0.01
Solids (Suspended)	20	46	11
Copper	0.008	0.011	0.006
Lead	<0.002	<0.002	<0.002
Zinc	0.028	0.05	0.024
Ammonia Nitrogen	0.19	0.21	0.42
Kjeldahl Nitrogen (Total)	1.0	1.2	0.7
Total Phosphorus	0.13	0.13	0.05
Hardness	44	50	24
Chloride	20.3	31.7	11.9
pH	7.38	7.42	7.42
NT = not tested, N/A = not applicable			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
	20-21-June-2020		
Constituent	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	1	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.5	0.3	0.3
Orthophosphate Phosphorus	0.02	0.01	<0.05
Solids (Suspended)	6	19	3
Copper	0.006	0.005	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.016	0.015	0.016
Ammonia Nitrogen	0.15	0.2	0.17
Kjeldahl Nitrogen (Total)	0.8	0.8	0.7
Total Phosphorus	0.07	0.04	0.03
Hardness	36	42	30
Chloride	17.1	25.8	14.9
pH	7.18	7.32	7.15
NT = not tested, N/A = not applicable			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	Station WC002	Station WC003	Station WC004
June 20-21, 2020 (Not Taken)			
TPH (mg/L)	NT	NT	NT
E. coli (MPN/100 ml)	NT	NT	NT
Temp (C)	NT	NT	NT
DO (mg/L)	NT	NT	NT
pH	NT	NT	NT
Sp. Cond. (mS/cm)	NT	NT	NT
NT = not tested			

Table A-5. Rainfall and flow statistics			
Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	1.57	1.57	1.57
Duration (hrs.)	8	8	14
Intensity (in./hr.)	0.196	0.196	0.112
Discharge (cf.)	576,309	181,006	86,088

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APPENDIX B

RATING CURVES

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Table B-1. Station WC002 rating curve from data points collected in 2019-2020	
Level (ft)	**Flow Rate (cfs)**
0.25	0.01
1.00	0.295
1.02	0.441
1.02	0.452
1.04	0.763
1.04	0.904
1.06	0.977
1.07	0.727
1.09	1.386
1.10	1.250
1.20	3.600
1.21	3.531
1.31	7.099
1.53	15.892
1.58	17.736

Table B-2. Station WC003 rating curve from data points collected in 2019-2020	
Level (ft)	**Flow Rate (cfs)**
0.62	0.058
0.62	0.067
0.64	0.071
0.66	0.154
0.67	0.222
0.70	0.180
0.79	0.389
0.82	0.439
0.85	0.664
0.90	1.093
0.99	1.929
1.03	2.389
1.11	3.390
1.28	8.454

Table B-3. Station WC004 rating curve from data points collected in 2019-2020	
Level (ft)	**Flow Rate (cfs)**
0.52	0.137
0.53	0.208
0.55	0.243
0.58	0.216
0.61	0.311
0.64	0.281
0.79	1.154
0.83	1.377
0.94	2.065
0.95	2.228
1.17	6.878
1.20	7.914

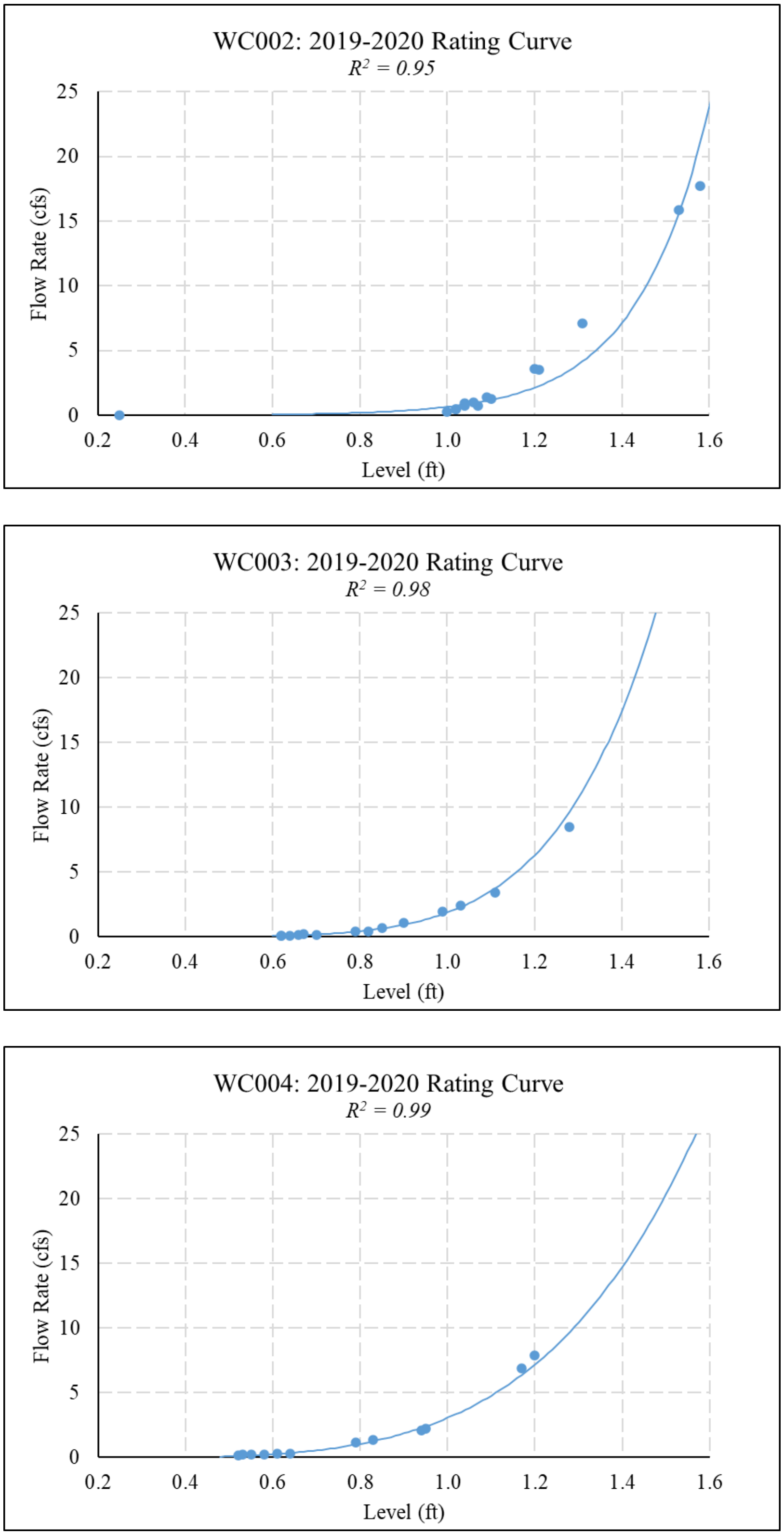

Figure B-1. Rating Curves for Stations WC002, WC003, and WC004

APPENDIX C

RAINFALL TOTALS

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Table C-1. July 2019-June 2020 rainfall data from USGS Atkisson logger (inches)												
Day	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
1	0	0.04	0	---	0.06	0.72	0	0.13	0	0	0.02	0
2	0.08	0	0.1	---	0	0.02	0	0	0.08	0	0	0
3	0.01	0	0.01	---	0	0	0.27	0	0.22	0	0.16	0
4	2.16	0	0	---	0	0.02	0.23	0.07	0	0	0.13	0.25
5	0.01	0	0	---	0	0	0	0.08	0	0	0	0.97
6	0.01	0	0	---	0	0	0	0.55	0.32	0	0.55	0
7	0.02	0.75	0	0.25	0.11	0	0.07	0.61	0.01	0	0	0
8	0.52	0	0	0.11	0	0	0.24	0	0	0.24	0.31	0
9	0	0	0	0.21	0	0.98	0	0	0	0.14	0	0
10	0	0	0	0	0	0.2	0	0.34	0.02	0	0	0.02
11	4.51	0	0.34	0	0	0.07	0	0.37	0	0	0.06	0.67
12	0	0	0.21	0	0.13	0	0.42	0.12	0	0.12	0	0
13	0	0.13	0	0	0	0.26	0	0.15	0.28	3.49	0	0
14	0	0.88	0	0	0	0.25	0.02	0	0.01	0.09	0	0
15	0	0	---	0	0	0	0	0	0.11	0.04	0.01	0
16	0	0	---	1.18	0	0.38	0	0	0	0	0	0
17	0.96	0	---	0	0	0.62	0	0	0.01	0	0	0.04
18	0.07	0.33	---	0	0.01	0	0.36	0	0.09	0.05	0	0.04
19	0	0.01	---	0	0.04	0	0.15	0	0.56	0	0	0.04
20	0	0	---	0.72	0	0	0	0	0.01	0	0	1.38
21	0	0	---	0	0	0	0	0	0	0.06	0	0
22	0.04	1.27	---	0.82	0.04	0	0	0	0	0	1.22	0.1
23	0.48	0.25	---	0.01	0.22	0	0	0	0.55	0.52	0.21	0.06
24	0	0	---	0	0.85	0	0	0	0	0.61	0	0.01
25	0	0	---	0	0	0	1.87	0.22	0.19	0.01	0	0
26	0	0	---	0	0	0	0	0.34	0	0.59	0	0
27	0	0	---	2.13	0	0	0	0.22	0.01	0.02	0	0.01
28	0	0.02	---	0	0	0	0	0	0.81	0	0.09	0
29	0.16	0	---	0	0	0.69	0		0	0.01	0	0
30	0	0	---	0.25	0	0.35	0		0	1.7	0	0
31	0	0		1.67		0	0.03		0.03		0	
Total Rain	**9.03**	**3.68**	**0.66**	**7.35**	**1.46**	**4.56**	**3.66**	**3.20**	**3.31**	**7.69**	**2.76**	**3.59**
Annual Rainfall Total:												**50.95**
"---" = gauge offline												

Table C-2. July 2019-June 2020 rainfall data from Wheel Creek HOBO logger (inches)												
Day	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
1	0.01	0.08	0.00	0.00	0.01	0.68	0.00	0.12	0.00	0.00	0.02	0.00
2	0.09	0.00	0.09	0.00	0.00	0.02	0.00	0.00	0.08	0.00	0.00	0.00
3	0.00	0.00	0.01	0.03	0.00	0.00	0.24	0.00	0.19	0.00	0.23	0.00
4	2.39	0.00	0.00	0.01	0.00	0.01	0.21	0.06	0.01	0.00	0.06	0.50
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.66
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.29	0.00	0.45	0.01
7	0.05	0.72	0.00	0.36	0.09	0.00	0.04	0.55	0.01	0.00	0.00	0.00
8	0.42	0.00	0.00	0.03	0.00	0.00	0.16	0.00	0.00	0.20	0.26	0.00
9	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.11	0.00	0.00
10	0.00	0.00	0.00	0.01	0.00	0.17	0.03	0.32	0.02	0.00	0.00	0.02
11	3.98	0.00	0.36	0.00	0.00	0.05	0.00	0.37	0.00	0.00	0.05	0.82
12	0.00	0.00	0.21	0.00	0.12	0.00	0.23	0.11	0.00	0.35	0.00	0.00
13	0.00	0.89	0.02	0.00	0.00	0.23	0.00	0.13	0.26	3.30	0.00	0.00
14	0.00	0.11	0.00	0.00	0.00	0.21	0.01	0.00	0.02	0.11	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.00
16	0.00	0.00	0.00	1.15	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00
17	0.94	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.01	0.00	0.00	0.04
18	0.08	0.16	0.00	0.00	0.01	0.00	0.00	0.00	0.17	0.04	0.00	0.11
19	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.46	0.00	0.00	0.06
20	0.00	0.02	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.57
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
22	0.03	1.01	0.00	0.72	0.03	0.00	0.00	0.00	0.00	0.00	1.21	0.00
23	0.40	0.24	0.00	0.00	0.23	0.00	0.00	0.00	0.53	0.57	0.20	0.00
24	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.57	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.20	0.18	0.02	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.01	0.48	0.00	0.00
27	0.00	0.00	0.00	1.99	0.00	0.00	0.00	0.17	0.00	0.01	0.00	0.00
28	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.81	0.00	0.04	0.00
29	0.24	0.00	0.00	0.00	0.00	0.62	0.00		0.01	0.01	0.00	0.00
30	0.00	0.00	0.00	0.30	0.00	0.31	0.01		0.00	1.75	0.00	0.00
31	0.00	0.00		1.32		0.00	0.03		0.06		0.00	
Total Rain	**8.63**	**3.24**	**0.69**	**6.57**	**1.28**	**4.10**	**1.00**	**2.92**	**3.21**	**7.59**	**2.52**	**3.79**
											Annual Rainfall Total:	**45.54**

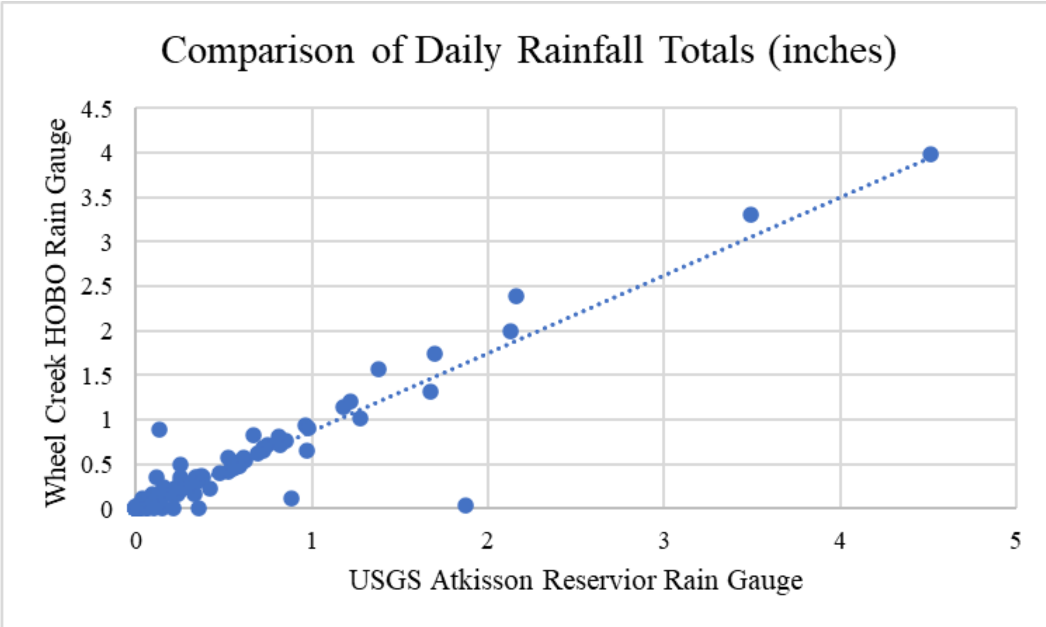

Figure C-1. Comparison of Daily Rainfall Totals for the USGS and Wheel Creek gauges

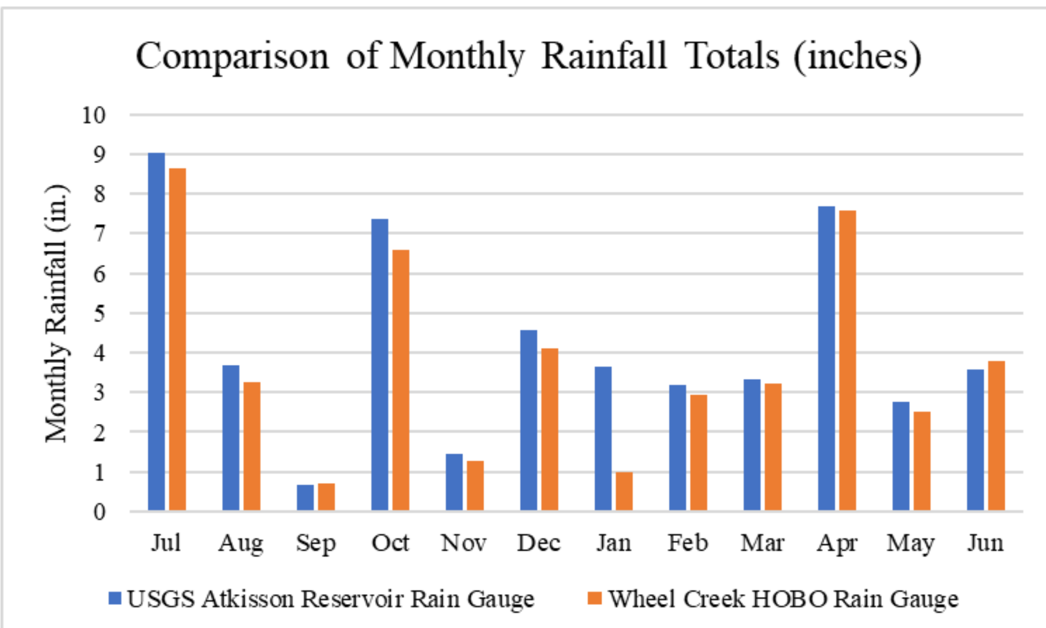

Figure C-2. Comparison of Monthly Rainfall Totals for the USGS and Wheel Creek gauges.

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APPENDIX D

TOTAL ANNUAL LOADS AND YIELDS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table D-1. Baseflow and storm flow MCs and EMCs, total annual loads, and annual yields (July 2019-June 2020)

Analyte	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Annual Storm Load (lbs)	Annual Baseflow Load (lbs)	Annual Total Load (lbs)	Yield (lbs/ac/yr)
Ammonia	WC002	0.127	0.234	203.544	237.994	441.537	1.317
	WC003	0.057	0.040	36.546	6.329	42.875	0.368
	WC004	0.092	0.026	26.433	5.051	31.484	0.807
BOD	WC002	2.710	0.417	4,340.286	423.476	4,763.762	14.207
	WC003	1.778	0.333	1,137.568	52.745	1,190.313	10.226
	WC004	1.788	0.250	512.048	48.879	560.928	14.383
Chloride	WC002	57.822	120.167	92,604.067	122,130.513	214,734.580	640.425
	WC003	65.077	141.167	41,643.536	22,337.316	63,980.852	549.664
	WC004	53.715	238.917	15,379.844	46,712.065	62,091.909	1,592.100
Nitrate + Nitrite	WC002	0.697	1.525	1,116.775	1,549.923	2,666.698	7.953
	WC003	0.461	1.017	294.965	160.871	455.836	3.916
	WC004	0.418	2.967	119.809	580.031	699.840	17.945
TKN	WC002	0.906	0.358	1,450.423	364.189	1,814.613	5.412
	WC003	0.804	0.392	514.561	61.975	576.536	4.953
	WC004	0.761	0.350	217.843	68.431	286.274	7.340
Total P	WC002	0.111	0.009	177.547	8.724	186.270	0.556
	WC003	0.074	0.005	47.300	0.844	48.144	0.414
	WC004	0.041	0.004	11.801	0.749	12.551	0.322
Ortho-phosphate	WC002	0.010	-	16.286	-	16.286	0.049
	WC003	0.005	-	3.376	-	3.376	0.029
	WC004	0.004	-	1.116	-	1.116	0.029
TSS	WC002	22.034	6.500	35,288.087	6,606.227	41,894.314	124.946
	WC003	24.062	3.917	15,397.659	619.748	16,017.408	137.607
	WC004	17.088	2.417	4,892.690	472.497	5,365.187	137.569
Copper	WC002	6.165	0.325	9.874	0.330	10.204	0.030
	WC003	5.889	0.433	3.768	0.069	3.837	0.033
	WC004	5.725	0.475	1.639	0.093	1.732	0.044
Lead	WC002	0.685	0.040	1.098	0.041	1.138	0.003
	WC003	0.541	0.052	0.346	0.008	0.354	0.003
	WC004	0.751	0.022	0.215	0.004	0.219	0.006
Zinc	WC002	30.456	10.000	48.777	10.163	58.940	0.176
	WC003	26.649	14.417	17.053	2.281	19.334	0.166
	WC004	33.447	21.833	9.577	4.269	13.845	0.355

"-" = Not Detected

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APPENDIX E

TOTAL SEASONAL LOADS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table E-1. Baseflow and storm flow MCs and EMCs and total seasonal load (July 2019-June 2020)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Ammonia							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	0.099	0.080	36.152	18.761	54.914
		WC003	0.017	0.023	2.287	0.834	3.120
		WC004	0.046	0.027	3.169	1.133	4.302
2020	Winter	WC002	0.114	0.257	35.361	61.497	96.858
		WC003	0.014	0.050	1.920	2.046	3.966
		WC004	0.043	0.040	3.118	1.814	4.932
	Spring	WC002	0.196	0.383	98.312	97.099	195.410
		WC003	0.180	0.087	34.146	4.231	38.377
		WC004	0.234	0.037	18.285	2.211	20.495
BOD							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	2.727	0.333	994.600	78.172	1,072.772
		WC003	1.500	0.667	200.626	23.819	224.445
		WC004	1.429	-	98.310	-	98.310
2020	Winter	WC002	1.455	0.333	451.652	79.866	531.518
		WC003	0.977	0.333	135.111	13.642	148.753
		WC004	2.310	0.667	168.769	30.231	199.000
	Spring	WC002	3.932	0.667	1,969.746	168.867	2,138.613
		WC003	3.134	0.333	593.229	16.271	609.501
		WC004	1.986	0.333	154.880	20.096	174.976
Chloride							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	50.658	119.667	18,478.293	28,063.919	46,542.212
		WC003	50.618	137.000	6,769.426	4,894.859	11,664.286
		WC004	29.683	265.333	2,042.410	11,276.161	13,318.571
2020	Winter	WC002	108.425	117.333	33,666.943	28,112.812	61,779.755
		WC003	131.180	138.000	18,141.792	5,647.879	23,789.671
		WC004	136.082	225.333	9,944.084	10,218.226	20,162.310
	Spring	WC002	21.547	116.000	10,793.097	29,382.925	40,176.022
		WC003	27.893	136.667	5,280.665	6,671.247	11,951.913
		WC004	19.409	211.000	1,513.451	12,720.773	14,234.225

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Nitrate + Nitrite							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	0.588	1.533	214.487	359.593	574.080
		WC003	0.355	0.967	47.410	34.538	81.948
		WC004	0.333	3.333	22.920	141.660	164.581
2020	Winter	WC002	1.148	1.667	356.314	399.330	755.644
		WC003	0.806	1.133	111.463	46.384	157.847
		WC004	0.696	2.867	50.829	129.995	180.824
	Spring	WC002	0.466	1.467	233.281	371.508	604.789
		WC003	0.329	0.967	62.250	47.187	109.437
		WC004	0.312	2.500	24.324	150.720	175.044
Orthophosphate							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	0.001	-	0.377	-	0.377
		WC003	0.004	-	0.473	-	0.473
		WC004	-	-	-	-	-
2020	Winter	WC002	0.002	-	0.653	-	0.653
		WC003	-	-	-	-	-
		WC004	0.005	-	0.359	-	0.359
	Spring	WC002	0.037	-	18.287	-	18.287
		WC003	0.014	-	2.654	-	2.654
		WC004	0.011	-	0.832	-	0.832
TKN							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	0.927	0.500	338.054	117.259	455.313
		WC003	0.813	0.500	108.693	17.864	126.558
		WC004	0.808	0.433	55.596	18.416	74.012
2020	Winter	WC002	0.489	0.333	151.824	79.866	231.690
		WC003	0.450	0.400	62.234	16.371	78.604
		WC004	0.656	0.400	47.902	18.139	66.041
	Spring	WC002	1.280	0.433	641.199	109.764	750.963
		WC003	1.141	0.433	216.006	21.153	237.158
		WC004	0.772	0.400	60.179	24.115	84.294

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Total Phosphorous							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	0.097	0.005	35.304	1.251	36.554
		WC003	0.066	0.003	8.788	0.119	8.908
		WC004	0.036	-	2.486	-	2.486
2020	Winter	WC002	0.016	0.016	5.098	3.754	8.851
		WC003	0.014	0.008	1.885	0.327	2.212
		WC004	0.036	0.005	2.632	0.242	2.874
	Spring	WC002	0.233	0.013	116.938	3.377	120.315
		WC003	0.151	0.010	28.513	0.488	29.001
		WC004	0.057	0.010	4.412	0.603	5.015
TSS							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	22.628	3.333	8,254.008	781.725	9,035.733
		WC003	17.596	11.000	2,353.263	393.018	2,746.281
		WC004	9.823	6.333	675.900	269.155	945.054
2020	Winter	WC002	1.719	0.667	533.688	159.732	693.419
		WC003	2.112	1.000	292.088	40.927	333.015
		WC004	36.472	-	2,665.142	-	2,665.142
	Spring	WC002	41.161	1.667	20,617.327	422.168	21,039.496
		WC003	58.944	-	11,159.183	-	11,159.183
		WC004	12.233	0.667	953.906	40.192	994.098
Copper							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	5.360	-	1.955	-	1.955
		WC003	4.888	0.400	0.654	0.014	0.668
		WC004	5.616	0.300	0.386	0.013	0.399
2020	Winter	WC002	1.785	0.200	0.554	0.048	0.602
		WC003	1.538	0.400	0.213	0.016	0.229
		WC004	5.372	0.533	0.393	0.024	0.417
	Spring	WC002	12.156	0.467	6.089	0.118	6.207
		WC003	12.241	0.467	2.318	0.023	2.340
		WC004	6.298	0.533	0.491	0.032	0.523

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (µg/L)	Baseflow MC (µg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Lead							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	0.492	-	0.180	-	0.180
		WC003	0.476	0.067	0.064	0.002	0.066
		WC004	0.217	0.033	0.015	0.001	0.016
2020	Winter	WC002	-	0.030	-	0.007	0.007
		WC003	-	0.020	-	0.001	0.001
		WC004	2.212	-	0.162	-	0.162
	Spring	WC002	1.757	0.033	0.880	0.008	0.889
		WC003	1.212	0.033	0.229	0.002	0.231
		WC004	0.357	0.020	0.028	0.001	0.029
Zinc							
2019	Summer	WC002	NS	NS	NS	NS	NS
		WC003	NS	NS	NS	NS	NS
		WC004	NS	NS	NS	NS	NS
	Fall	WC002	31.315	11.667	11.423	2.736	14.159
		WC003	25.364	18.000	3.392	0.643	4.035
		WC004	34.247	27.667	2.356	1.176	3.532
2020	Winter	WC002	12.875	10.000	3.998	2.396	6.394
		WC003	13.573	14.667	1.877	0.600	2.477
		WC004	41.666	23.000	3.045	1.043	4.088
	Spring	WC002	46.320	9.000	23.202	2.280	25.481
		WC003	42.296	12.333	8.007	0.602	8.609
		WC004	23.625	18.000	1.842	1.085	2.927

NS = Not Sampled; no storms were monitored in the Summer season in the 2019-2020 reporting period.
“-“ = Not Detected

Wheel Creek

Year 12 – 2020 Biological and Physical Habitat Monitoring Results

December | 2020

Prepared For

Harford County

Watershed Protection and Restoration

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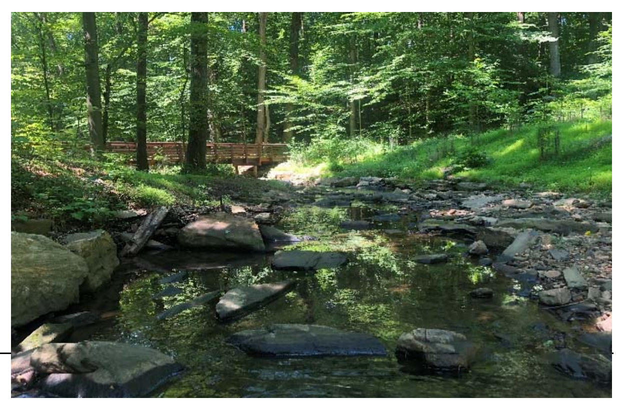

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1. Background

Harford County commissioned a small watershed action plan for a small subwatershed in the Bush River watershed. The Wheel Creek Small Watershed Action Plan (BayLand, 2008) was completed in August of 2008. Projects identified in the plan were submitted by the County for funding by the Chesapeake and Atlantic Coastal Bays Trust Fund (Trust Fund). Wheel Creek was one of the first project areas selected for funding for restoration by the Trust Fund. In 2009, the County began intensive monitoring of water quality, geomorphology, and ecological condition in the Wheel Creek watershed as projects were implemented. The first restoration project was completed during 2012 and the last projects were completed in July of 2017.

Wheel Creek is an unnamed tributary to Winters Run at Atkisson Reservoir south of Bel Air, MD. It is a small subwatershed, approximately 393 acres in size (Becker, 2010). Land use in Wheel Creek watershed is dominated by urban development at 46.1% with forest at 34.7% and agriculture at 19.0%. Impervious surfaces in the watershed cover 21.4% of the watershed area. Harford County Public Schools own the only parcel of substantial forest, on the Harford Glen property.

Maryland Department of Natural Resources' (MD DNR) Maryland Biological Stream Survey (MBSS) monitored seven sites in Wheel Creek and one additional local urban reference site as part of this effort. The MBSS was responsible for the collection and analyzation of the data during 2009 to 2018. All sites were sampled through 2017. The four upstream most sites were discontinued prior to the 2018 sampling year. Sampling at the remaining three downstream Wheel Creek sites and the urban control site was continued by DNR through 2019.

KCI Technologies, Inc. completed the twelfth year of chemical, physical, and biological stream sampling in spring and summer of 2020 at the four remaining stream sites in Wheel Creek. This technical memorandum describes the methods and results of the 2020 sampling conducted at those sites in the Wheel Creek watershed.

The primary goal of this effort is to characterize baseline stream conditions (biological, physical habitat, and *in situ* chemical) prior to additional restoration project/BMP implementation. A secondary goal is to conduct monitoring in Wheel Creel that can be used to document ecological uplift and habitat improvement as projects are completed within this watershed.

2. Methods

The monitoring effort includes chemical (*in situ* water quality), physical (habitat assessment), and biological (benthic macroinvertebrate, fish, herpetofauna, freshwater mussels, and crayfish) assessments conducted at each of the selected sites. The sampling methods used are consistent with Maryland Department of Natural Resources' (DNR) Maryland Biological Stream Survey (MBSS). The methods have been developed locally and are calibrated specifically to Maryland's ecophysiographic regions and stream types.

2.1 Sampling Sites

Four sampling sites were selected within the Wheel Creek watershed (Figure 1) to characterize baseline stream conditions and to assess the effect of planned restoration on the ecological health of the watershed. A brief description of sites follows;

2.1.1 ATKI-101-X

The lowest downstream site in Wheel Creek is ATKI-101-X and it is located near the USGS gage on Wheel Creek. This site has been monitored continuously since 2009 and was continuously monitored by MBSS until 2018. The land use upstream of ATKI-101-X is mostly urban (46.1%) with the remaining portion in forest (34.7%) and agriculture (19.0%).

2.1.2 ATKI-102-X

ATKI-102-X is located on the furthest reach downstream on the west branch of Wheel Creek, a short distance upstream of Wheel Road. The catchment upstream of this site is mostly urban (65.7%) with the remaining land classified as agriculture (18.6%) and forest (15.7%).

2.1.3 ATKI-003-X

ATKI-003-X is located on the furthest downstream site on the east branch. Nearby, ATKI-102-X is a short distance upstream of Wheel Road. The upstream catchment to this site is mostly urban (57.5%) with the remaining land classified as forest (27.8%) and agriculture (14.1%).

2.1.4 LWIN-108-X

An urban control site is located nearby on an unnamed tributary to Winters Run downstream of the Atkinson Reservoir. This site was first sampled in 2009 and was continuously monitored by MBSS until 2018. The land use upstream of this site is mostly urban (50.5%) with the remaining portion in agriculture (26.1%) forest (23.4%).

2.2 Water Quality

Water quality conditions were measured *in situ* during the summer 2020 sampling visits at all Wheel Creek sites. Currently the MBSS does not measure *in situ* water quality at sites, but did so in the past. *In situ* water quality methods used were consistent with those in DNR, 2010. Field measured parameters include temperature, dissolved oxygen, pH, specific conductance, and turbidity. Measurements at each site were made at the upstream end of the 75-meter long site. *In situ* measurements were made before any sampling activities started to avoid sampling water disturbed by other activities. Most *in situ* parameters (i.e., temperature, pH, specific conductivity, and dissolved oxygen) were measured using a multiparameter sonde (YSI Professional Plus), while turbidity was measured with a Hach 2100 Turbidimeter. Water quality meters are regularly inspected and maintained and were calibrated immediately prior to sampling to ensure proper usage and accuracy of the readings.

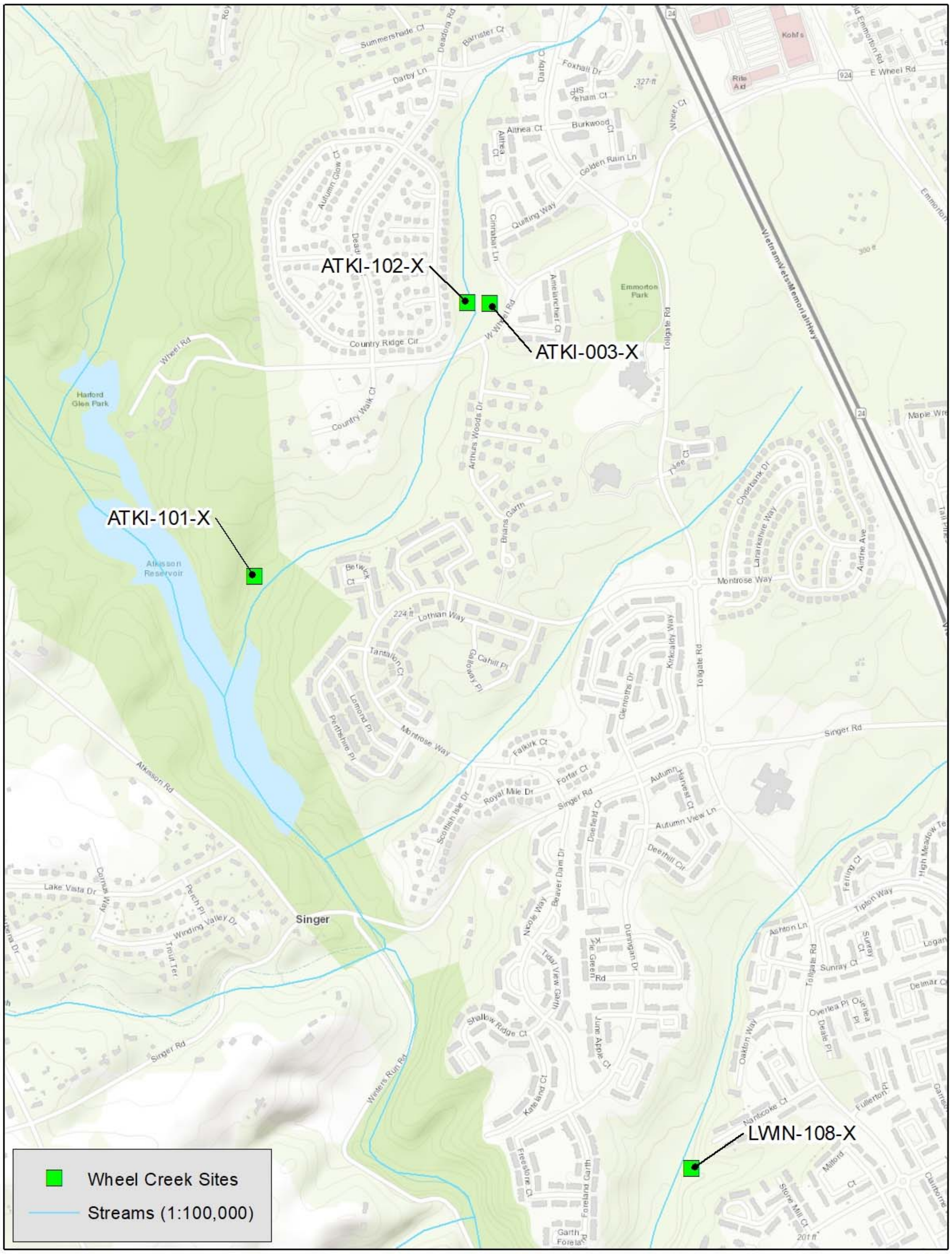

Figure 1 – Location of Sampling Sites

2.3 Physical Habitat Assessment

Each stream site was characterized based on visual observations of physical characteristics and various habitat parameters. The Maryland Biological Stream Survey's (MBSS) Physical Habitat Index (PHI; Paul et al. 2002) was used to assess the physical habitat at the site. The majority of the habitat perameters were collected during the summer visits, on June 26, 2020 and July 2, 2020.

To reduce individual sampler bias, assessments were completed as a team with discussion and agreement of the scoring for each parameter. In addition to the visual assessments, photographs were taken from three locations within each sampling reach (downstream end, midpoint, and upstream end) facing in the upstream and downstream direction, for a total of six (6) photographs per site.

The PHI incorporates the results of a series of habitat parameters selected for Coastal Plain, Piedmont and Highlands regions. While all parameters are rated during the field assessment, the Piedmont parameters were used to develop the PHI score for these sites because the Wheel Creek watershed is located in Maryland's Piedmont ecophysiographic region. In developing the PHI, MBSS identified eight parameters that have the most discriminatory power for the Piedmont streams. These parameters are used in calculating the PHI (Table 1). Several of the parameters have been found to be drainage area dependent and are scaled accordingly. The drainage area to each site was calculated in GIS by MBSS. We are using the same catchments for each site to remain consistent with MBSS.

Table 1 – PHI Piedmont Parameters

Piedmont Stream Parameters	
Instream Habitat	Epifaunal Substrate
Bank Stability	Percent Shading
Remoteness	Number Woody Debris/Root wads

Each habitat parameter is given an assessment score ranging from 0-20, with the exception of shading (percentage 0-100%) and woody debris and root wads (total count). A prepared score and scaled score (0-100) are then calculated. The average of these scores yields the final PHI score. The final scores are then ranked according to the ranges shown in Table 2 and assigned corresponding narrative ratings, which allows for a score that can be compared to habitat assessments performed statewide.

Table 2 – PHI Score and Ratings

PHI Score	Narrative Rating
81.0 – 100.0	Minimally Degraded
66.0 – 80.9	Partially Degraded
51.0 – 65.9	Degraded
0.0 – 50.9	Severely Degraded

2.4 Benthic Macroinvertebrate Community Assessment

Benthic macroinvertebrate collection strictly followed MBSS procedures (Stranko et al. 2019). Sampling occurred during the Spring Index Period (March 1 – April 30), samples were collected from all four Wheel Creek sites on April 29, 2020. The monitoring sites consist of a 75-meter reach and benthic macroinvertebrate sampling is conducted once per year. The sampling methods utilize semi-quantitative field collections of the benthic macroinvertebrate community. The multi-habitat D-frame net approach is used to sample a range of the most productive habitat types present within the reach. Best available habitats include riffles, stable woody debris, root wads, root mats, leaf packs, aquatic macrophytes, and undercut banks. In this sampling approach, a total of twenty kicks or jabs (each approximately one square foot) are distributed proportionally among all best available habitats within the stream site and combined into a single composite sample and preserved in 95 percent ethanol. The composite sample contains material collected from approximately 20 square feet of habitat.

MBSS specifies that a minimum of 5% (1 in 20) of sites are selected for a duplicate sample (Stranko et al. 2019). Because the total number of samples in this project (4) is well below 20, Wheel Creek samples were pooled with other County monitoring project samples from Foster Branch (5) and Plum Tree (5) to meet the field sampling QC objective (1 in 14, or 7.14%). The randomly selected QC site for 2020 was taken at Plum-2.

2.4.1 Benthic Macroinvertebrate Sample Processing and Laboratory Identification

Benthic macroinvertebrate samples were processed and subsampled according to methods described in the MBSS Laboratory Methods for Benthic Macroinvertebrate Processing and Taxonomy (Boward and Friedman 2019). Subsampling was conducted to standardize the sample size and reduce variation caused by samples of different size. In this method, the sample was spread evenly across a numbered, gridded tray (100 total grids), and a grid was picked at random and picked clean of organisms. If the organism count was 100 or more, then the subsampling was complete. If the organism count was less than 100, then another grid was selected at random and picked clean of organisms. This repeated until the organism count reached 100 to 120 organisms. The 100 (plus 20 percent) organism target is used to allow for specimens that are missing parts or are not mature enough for proper identification, are terrestrial, or meiofauna. Identification of the subsampled specimens was conducted by Environmental Services and Consulting, Inc. Taxa were identified to the genus level for most organisms. Groups including Oligochaeta and Nematomorpha were identified to the family level while Nematomorpha was left at phylum. Individuals of early instars or those that were damaged were identified to the lowest possible level, which could be phylum or order, but in most cases was family. Chironomidae could be further subsampled depending on the number of individuals in the sample and the numbers in each subfamily or tribe. Most taxa were identified using a stereoscope. Temporary slide mounts viewed with a compound microscope were used to identify Oligochaeta to family and for Chironomid sorting to subfamily and tribe. Permanent slide mounts were then used for Chironomid genus level identification. Results were logged on a bench sheet and entered into a spreadsheet for analysis.

Benthic macroinvertebrate lab quality control procedures followed those used by the MBSS (Boward and Friedman 2019). Because the total number of samples in this project (4) is well below 20, Wheel Creek samples were pooled with samples from Foster Branch (5) and Plum Tree (5) to meet the laboratory QC objective (1 in 14, or 7.14%). The lab QC samples were selected at random from either Foster Branch, Plumtree Run, or Wheel Creek samples. One (1) sample was randomly selected for QC re-identification by an independent lab.

2.4.2 Benthic Macroinvertebrate Data Analysis

Benthic macroinvertebrate data were analyzed by KCI using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The Benthic Index of Biotic Integrity (BIBI) approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. The metrics selected fall into five major groups including taxa richness, composition measures, tolerance to perturbation, trophic classification, and habit measures. Raw values from each metric were given a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled IBI score from 1.0 to 5.0, and a corresponding narrative biological condition rating was applied.

Three sets of metric calculations have been developed for Maryland streams based on broad eco-physiographic regions. These include the Coastal Plain, Piedmont and combined Highlands. The study area is located in the Piedmont region therefore the following metrics (Table 3) and IBI scoring (Table 4) were used for the analysis.

Table 3 – Benthic Macroinvertebrate Metric Scoring for the Piedmont BIBI

Metric	Score		
	5	3	1
Total Number of Taxa	≥ 25	15 – 24	< 15
Number of EPT Taxa	≥ 11	5 – 10	< 5
Number of Ephemeroptera Taxa	≥ 4	2 – 3	< 2
% Intolerant to Urban	≥ 51	<51 – 12	< 12
% Chironomidae	≤ 24	>24 – 63	> 63
% Clingers	≥ 74	<74 – 31	< 31

*Adjusted for catchment size

Table 4 – BIBI Condition Ratings

IBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

2.5 Fish Community Assessment

The fish community at each of the four Wheel Creek sites was sampled during the Summer Index Period, June 1 through September 30, according to methods described in *Maryland Biological Stream Survey: Round Four Field Sampling Manual* (Stranko et al. 2019). These data were collected at the four Wheel Creek sites on June 26, 2020 and July 2, 2020. In general, the approach uses two-pass electrofishing of the entire 75-meter study reach. Block nets were placed at the upstream and downstream ends of the reach, as well as at tributaries or outfall channels, to obstruct fish movement into or out of the study reach. Two passes were completed along the reach to ensure the segment was adequately sampled. The time in seconds for each pass was recorded and the level of effort for each pass was similar. Captured fish were identified to species and enumerated following MBSS protocols (Stranko et al. 2019). A total fish biomass for each electrofishing pass was measured. Unusual anomalies such as fin erosion, tumors, etc. were recorded. Photographic vouchers were taken in lieu of voucher specimens.

2.5.1 Fish Data Analysis

Fish data for Wheel Creek sites were analyzed using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The IBI approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. Raw values from each metric were assigned a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled FIBI score, ranging from 1.0 to 5.0, and a corresponding narrative rating of 'Good', 'Fair', 'Poor' or 'Very Poor' was applied, again in accordance with standard practice.

Four sets of FIBI metric calculations have been developed for Maryland streams. These include the Coastal Plain, Eastern Piedmont, and warmwater and coldwater Highlands. Wheel Creek is located in the Eastern Piedmont region, therefore, the following metrics listed in Table 5 were used for the FIBI scoring (Table 6) and analysis.

Table 5 – Fish Metric Scoring for the Piedmont FIBI

Metric	Score		
	5	3	1
Abundance per Square Meter	≥ 1.25	0.25 – 1.24	< 0.25
Number of Benthic species *	≥ 0.26	<0.26 – 0.09	< 0.09
% Tolerant	≤ 45	>45 – 68	> 68
% Generalist, Omnivores, Invertivores	≤ 80	>80 – 99.9	>99.9
Biomass per Square Meter	≥ 8.6	<8.6 – 4.0	< 4.0
% Lithophilic Spawners	≥ 61	<60 – 32	< 32

*Adjusted for catchment size

Table 6 – FIBI Condition Ratings

IBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

2.6 Herpetofauna Survey

Herpetofauna (i.e., reptiles and amphibians) were surveyed at each of the four Wheel Creek sites using methods following MBSS protocols (Stranko et al. 2019). All collected individuals were identified to species level and released. Photographic vouchers were collected if a specimen could not be positively identified in the field.

Herpetofauna data collection occurs primarily to assist MBSS with supplementing their inventory of biodiversity in Maryland's streams. Currently, MBSS has not developed any indexes of biotic integrity for herpetofauna, and therefore, they were not used to evaluate the biological integrity of sampling sites throughout this study. Rather, the data are provided to help document existing conditions.

2.7 Freshwater Mussel Survey

A survey of freshwater mussels was conducted at each site using MBSS protocols (Stranko et al. 2019). A search for freshwater mussels was conducted at each site. Any live individuals encountered were identified, photographed, and then returned back to the stream as closely as possible to where they were collected. Any dead shells were retained as voucher specimens.

2.8 Crayfish Survey

Crayfish were surveyed for at each site using MBSS protocols (Stranko et al. 2019). All crayfish observed while electrofishing were captured and retained until the end of each electrofishing pass. Captured crayfish were identified to species and counted before release back into the stream outside of the 75-meter sampling reach. Any crayfish encountered outside of the electrofishing effort were identified and noted on the datasheet as an incidental observation. Any crayfish burrows observed in and around the sampling site were excavated and an attempt made to capture the burrowing crayfish.

2.9 Invasive Plant Survey

A survey of invasive plants was performed at each site during the Summer Index Period following MBSS protocols (Stranko et al. 2019). The common name and relative abundance of invasive plants (i.e., present or extensive) within view of the study reach and within the 5-meter riparian vegetative zone parallel the stream channel were recorded.

Invasive plant data collection occurs to assist MBSS with supplementing their inventory of biodiversity. The data are provided to help document existing conditions at each site.

2.10 Quality Assurance and Quality Control

All work was conducted with thorough quality assurance and quality control. Biological assessment methods have been designed to be consistent and comparable with the methods used by MBSS (Stranko et al. 2019). Field crews receive yearly training in MBSS protocols and certification by DNR to perform benthic macroinvertebrate and fish sampling procedures. All field forms are checked and signed by the Crew Leader before leaving the site. Digital data entry is also checked for accuracy. Field equipment are checked regularly and calibrated as necessary prior to use. Calculation of metric scores and IBIs are completed using KCI's controlled and verified spreadsheet and each site undergoes a documented quality control check.

3. Results

Biological monitoring and water quality sampling were conducted to assess the conditions in the Wheel Creek watershed. Presented below are the summary results for each monitoring component.

3.1 Water Quality

Water quality measurements were collected during the Summer Index Period sampling visit at each of the four Wheel Creek sites. Table 7 presents the results of the *in situ* water quality measurements.

Table 7 – In Situ Water Quality Measurement Results for 2020

Site	Season	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Units)	Specific Conductance (µS/cm)	Turbidity (NTU)
ATKI-101-X	Summer 2020	19.3	10.01	7.88	452.2	1.82
ATKI-102-X	Summer 2020	19.0	7.88	7.65	480.9	2.38
ATKI-003-X	Summer 2020	23.5	8.31	8.11	502.1	4.35
LWIN-108-X	Summer 2020	19.1	10.51	7.51	394.0	2.58

Shaded cells indicate values exceeding either water quality criteria or published values

MDE has established acceptable water quality standards for each designated Stream Use Classification, which are listed in the *Code of Maryland Regulations (COMAR) 26.08.02.03-.03 - Water Quality*. Wheel Creek is covered in *COMAR* in Sub-Basin 02-13-07: Bush River Area as Use IV-P waters. Specific designated uses for Use IV-P streams include public water supply, supporting adult trout for put-and-take fishing, growth and propagation of fish and aquatic life, water supply for industrial and agricultural use, water contact sports, fishing, and leisure activities involving direct water contact.

The acceptable criteria for Use IV-P waters are as follows:

- pH - 6.5 to 8.5
- DO - may not be less than 5 mg/l at any time
- Turbidity - maximum of 150 Nephelometric Turbidity Units (NTU's) and maximum monthly average of 50 NTU
- Temperature - maximum of 75°F (23.9°C) or ambient temperature of the surface water, whichever is greater

In situ water quality measurements for temperature, dissolved oxygen, pH, and turbidity were within COMAR standards for Use IV-P streams. Although MDE does not have a water quality standard for specific conductivity, Morgan and others (Morgan et al, 2007; Morgan et al, 2012) have reported critical values for specific conductance in Maryland streams, above which there is a potential for detrimental effects on the stream biological communities. For the benthic macroinvertebrate community that critical value is 247 µS/cm, and for the fish community it is 171 µS/cm. Each of the four Wheel Creek stream sites had specific conductivity values far exceeding the threshold for both benthic macroinvertebrate and fish community impairments for all water quality sampling events. Conductivity levels in this watershed are likely influenced by runoff from impervious surfaces (i.e., roads, sidewalks, parking lots, roof tops). Increased stream inorganic ion concentrations (i.e., conductivity) in urban systems typically results from paved surface de-icing, accumulations in storm-water management facilities (Casey et al. 2013), runoff over impervious surfaces, passage through pipes, and exposure to other infrastructure (Cushman 2006). While elevated conductivity may not directly affect stream biota, its constituents (e.g., chloride, metals, and nutrients) may be present at levels that can cause biological impairment.

3.2 Physical Habitat Assessment

The summary results of the PHI habitat assessments for 2020 are presented in Table 8. All Wheel Creek sites have compromised physical habitat, with PHI ratings of 'Degraded' except for ATKI-101-X in 2020. ATKI-101-X had the best habitat score of the four sites with a 'Partially Degraded' rating. The relatively low habitat scores are likely due to urbanization effects on streams. Complete physical habitat data for each site are included in Appendix A.

Table 8 – RBP and PHI Habitat Assessment Results for 2020

Site	Season	PHI Score	PHI Narrative Rating
ATKI-101-X	Summer 2020	68.5	Partially Degraded
ATKI-102-X	Summer 2020	64.1	Degraded
ATKI-003-X	Summer 2020	53.1	Degraded
LWIN-108-X	Summer 2020	61.9	Degraded

3.3 Benthic Macroinvertebrate Community

The results of 2020 benthic macroinvertebrate community assessments are presented in Table 9. Complete benthic macroinvertebrate data for each site are included in Appendix B.

Table 9 – Benthic Index of Biotic Integrity (BIBI) Summary Data – 2020

Metric	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Metric Values				
Total Number of Taxa	19	19	18	23
Number of EPT Taxa	5	5	5	6
Number of Ephemeroptera Taxa	1	2	1	1
% Intolerant to Urban	3.79	0.00	2.17	5.26
% Chironomidae	59.85	63.95	86.23	84.21
% Clingers	0.00	0.00	15.22	25.56
Metric Scores				
Total Number of Taxa	3	3	3	3
Number of EPT Taxa	3	3	3	3
Number of Ephemeroptera Taxa	1	3	1	1
% Intolerant to Urban	1	1	1	1
% Chironomidae	3	1	1	1
% Clingers	1	1	1	1
BIBI Score	***2.00***	***2.00***	***1.67***	***1.67***
Narrative Rating	**Poor**	**Poor**	**Very Poor**	**Very Poor**

For 2020 benthic macroinvertebrate sampling, all four Wheel Creek sites had BIBI ratings in the 'Poor' or 'Very Poor' category, with ATKI-003-X and LWIN-108-X scoring 1.67, the lowest scores.

At the Wheel Creek sites BIBI scores ranged from 1.67 to 2.00. The individual metrics scored consistently low across all sites with none of the site receiving a score of 5 for any metrics. Two metrics, Percent Intolerant to Urban, and Percent Clingers scored consistently low across all four sites with each site scoring the lowest possible ‘1’ for these two metrics. Minor differences in the other four metrics (Total Number of Taxa, Number of EPT Taxa, Number of Ephemeroptera Taxa, and Percent Chironomidae) accounted for the variation in BIBI scores. These low BIBI scores are possibly due to poor habitat and water quality. All sites had measured specific conductivity values greater than the published impairment threshold for benthic macroinvertebrates.

A comparison of BIBI scores from 2009 to 2019 during the MBSS years of monitoring as well as 2020 is presented in Table 10 and Figure 2. Three of the four Wheel Creek sites had BIBI scores that were higher in 2020 than in the MBSS 2018 or 2019 season (ATKI-101-X, ATKI-102-X, LWIN-108-X), while ATKI-003-X remained the same between 2020 and 2018, but higher in 2020 than in 2019. Site LWIN-108-X had the largest BIBI score difference (+0.34), scoring a 1.33 in 2017 and a 1.67 in 2020. Sites ATKI-101-X, ATKI-102-X, and ATKI-003-X had the smallest BIBI score differences (+0.33).

Table 10 – BIBI Scores and Narrative Rating for MBSS monitoring years and for 2020.

Site	Year	BIBI Score	Narrative Rating
ATKI-101-X	Spring 2009	2.67	Poor
ATKI-101-X	Spring 2010	3.00	Fair
ATKI-101-X	Spring 2011	2.33	Poor
ATKI-101-X	Spring 2012	1.33	Very Poor
ATKI-101-X	Spring 2013	2.00	Poor
ATKI-101-X	Spring 2014	1.00	Very Poor
ATKI-101-X	Spring 2015	2.67	Poor
ATKI-101-X	Spring 2016	2.67	Poor
ATKI-101-X	Spring 2017	1.33	Very Poor
ATKI-101-X	Spring 2018	1.67	Very Poor
ATKI-101-X	Spring 2019	1.67	Very Poor
ATKI-101-X	Spring 2020	2.00	Poor
ATKI-102-X	Spring 2009	2.00	Poor
ATKI-102-X	Spring 2010	1.67	Very Poor
ATKI-102-X	Spring 2011	1.33	Very Poor
ATKI-102-X	Spring 2012	1.67	Very Poor
ATKI-102-X	Spring 2013	1.67	Very Poor
ATKI-102-X	Spring 2014	2.00	Poor
ATKI-102-X	Spring 2015	2.00	Poor
ATKI-102-X	Spring 2016	2.67	Poor
ATKI-102-X	Spring 2017	1.67	Very Poor
ATKI-102-X	Spring 2018	1.67	Very Poor
ATKI-102-X	Spring 2019	1.00	Very Poor
ATKI-102-X	Spring 2020	2.00	Poor
ATKI-003-X	Spring 2009	2.00	Poor
ATKI-003-X	Spring 2010	1.67	Very Poor
ATKI-003-X	Spring 2011	1.33	Very Poor
ATKI-003-X	Spring 2012	2.67	Poor
ATKI-003-X	Spring 2013	2.00	Poor
ATKI-003-X	Spring 2014	1.33	Very Poor
ATKI-003-X	Spring 2015	2.33	Poor
ATKI-003-X	Spring 2016	1.33	Very Poor
ATKI-003-X	Spring 2017	1.33	Very Poor
ATKI-003-X	Spring 2018	1.67	Very Poor
ATKI-003-X	Spring 2019	1.33	Very Poor
ATKI-003-X	Spring 2020	1.67	Very Poor
LWIN-108-X	Spring 2009	2.67	Poor
LWIN-108-X	Spring 2010	3.00	Fair
LWIN-108-X	Spring 2011	1.33	Very Poor
LWIN-108-X	Spring 2012	3.00	Fair
LWIN-108-X	Spring 2013	2.67	Poor
LWIN-108-X	Spring 2014	1.67	Very Poor
LWIN-108-X	Spring 2015	2.33	Poor
LWIN-108-X	Spring 2016	3.00	Fair
LWIN-108-X	Spring 2017	2.00	Poor
LWIN-108-X	Spring 2018	1.33	Very Poor
LWIN-108-X	Spring 2019	1.33	Very Poor
LWIN-108-X	Spring 2020	1.67	Very Poor

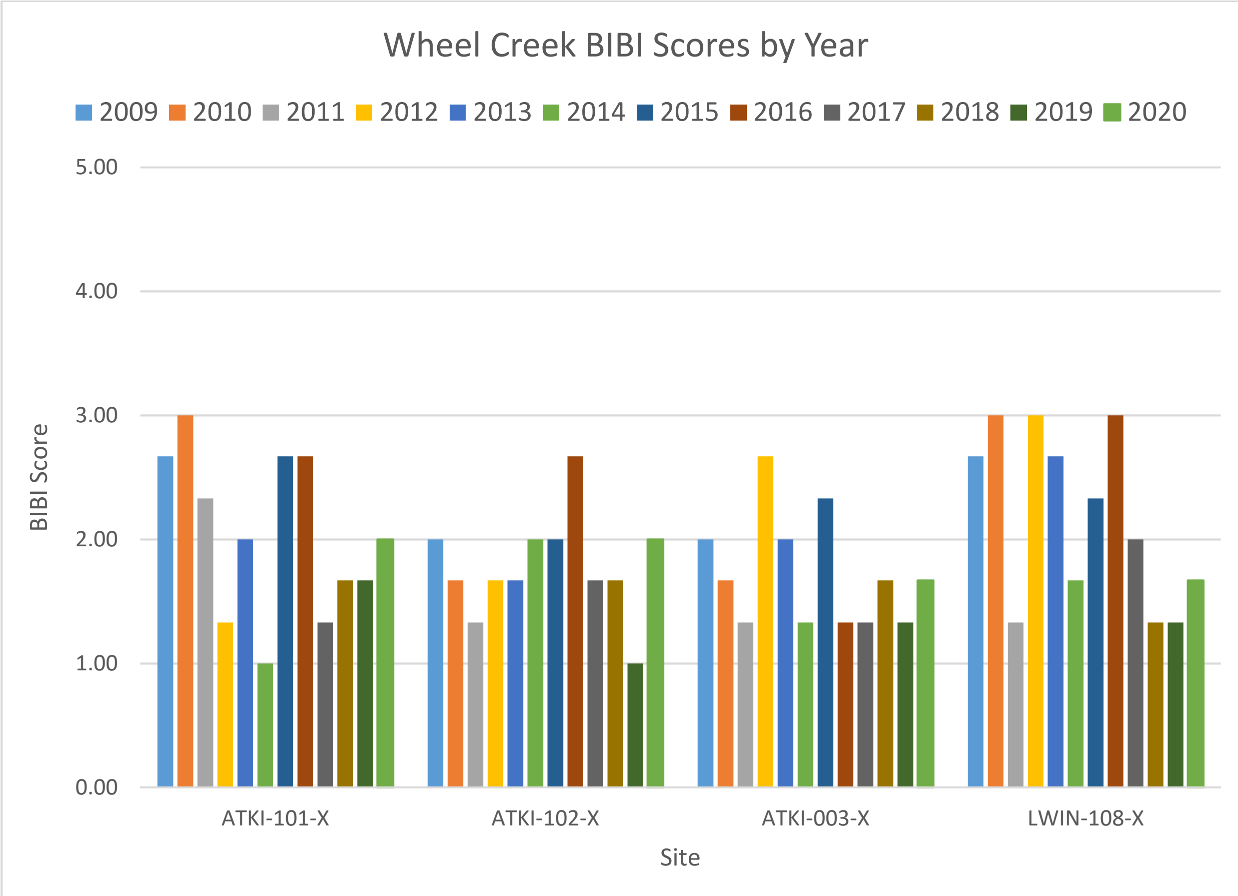

Figure 2 – BIBI Scores by Year

3.4 Fish Community

The results of the 2020 fish community assessments are presented in Table 11 and a list of species collected over the first sampling year at each site can be found in Table 12. Complete fish community data for each site are included in Appendix C.

Table 11 – Fish Index of Biotic Integrity (FIBI) Summary Data – 2020

Metric	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Metric Values				
Abundance per Square Meter	2.55	9.57	2.40	1.19
Adjusted Number of Benthic Species	2.26	2.89	6.00	2.20
% Tolerant	47.55%	89.35%	97.67%	31.54%
% Generalist, Omnivores, Invertivores	62.10%	89.35%	97.67%	47.71%
Biomass per Square Meter	8.10	20.25	9.53	6.17
% Lithophilic Spawners	56.20%	34.86%	48.06%	72.51%
Metric Scores				
Abundance per Square Meter	5	5	5	3
Adjusted Number of Benthic Species	5	5	5	5
% Tolerant	3	1	1	5
% Generalist, Omnivores, Invertivores	5	3	3	5
Biomass per Square Meter	3	5	5	3
% Lithophilic Spawners	3	3	3	5
FIBI Score	***4.00***	***3.67***	***3.67***	***4.33***
Narrative Rating	***Good***	***Fair***	***Fair***	***Good***

Table 12 –List of Fish Species Collected at Wheel Creek Sites - 2020

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
White Sucker	*Catostomus commersonii*	X			X
Bluntnose Minnow	*Pimephales notatus*	X			X
Fathead Minnow	*Pimephales promelas*	X			
Common Shiner	*Luxilus cornutus*	X			X
Rosyside Dace	*Clinostomus funduloides*	X			X
Creek Chub	*Semotilus atromaculatus*	X	X	X	X
Fallfish	*Semotilus corporalis*	X			
Blacknose Dace	*Rhinichthys atratulus*	X	X	X	X
Longnose Dace	*Rhinichthys cataractae*	X			X
Eastern Mosquitofish	*Gambusia holbrooki*	X			
Blue Ridge Sculpin	*Cottus caeruleomentum*	X	X	X	X
Tessellated Darter	*Etheostoma olmstedi*	X			
Redbreast Sunfish	*Lepomis auritus*	X			
Bluegill	*Lepomis macrochirus*	X			
Pumpkinseed	*Lepomis gibbosus*	X			
Northern Hogsucker	*Hypentelium nigricans*				X
American Eel	*Anguilla rostrata*				X
Margined Madtom	*Noturus insignis*				X

The Wheel Creek sites had FIBI ratings ranging from ‘Fair’ to ‘Good’. Site LWIN-108-X had the highest FIBI score, 4.33 which rated ‘Good’. ATKI-101-X was rated as ‘Good’ with a score of 4.00. Sites ATKI-102-X and ATKI-003-X both received a rating of ‘Fair’, with scores of 3.67. Three species of fish have been collected at both ATKI-102-X and ATKI-003-X, 11 species collected at LWIN-108-X and 15 species collected at ATKI-

101-X which had the highest diversity of the four sites. Metrics for Adjusted Number of Benthic Species was consistent between the four sites. Percent tolerant varied the most between the sites, with LWIN-108-X scoring a ‘5’, ATKI-101-X scoring a ‘3’, and ATKI-102-X and ATKI-003-X scoring a ‘1’. Minor differences in the other three metrics between sites accounted for the minor variability in FIBI scores between sites.

A comparison of FIBI scores from 2009 to 2019 during the MBSS years of monitoring as well as 2020 of monitoring is presented in Table 10 and Figure 2. Three of the four Wheel Creek sites had FIBI scores that were the same as or higher in 2020 than in the MBSS 2018 or 2019 season (ATKI-101-X, ATKI-003-X, LWIN-108-X), while ATKI-102-X remained the same between the last several years. Site ATKI-101-X had the largest FIBI score difference (+1.00), scoring a 3.00 in 2018 and a 4.00 in 2020. Sites ATKI-003-X, and LWIN-108-X, had the smallest FIBI score differences (+0.34, +0.33 respectively), and ATKI-102-X had no change between the last four years.

Table 13 – FIBI Scores and Narrative Rating for MBSS monitoring years and 2020.

Site	Year	FIBI Score	Narrative Rating
ATKI-101-X	Summer 2009	4.67	Good
ATKI-101-X	Summer 2010	4.33	Good
ATKI-101-X	Summer 2011	4.33	Good
ATKI-101-X	Summer 2012	4.00	Good
ATKI-101-X	Summer 2013	4.67	Good
ATKI-101-X	Summer 2014	4.00	Good
ATKI-101-X	Summer 2015	3.33	Fair
ATKI-101-X	Summer 2016	4.33	Good
ATKI-101-X	Summer 2017	3.67	Fair
ATKI-101-X	Summer 2018	3.00	Fair
ATKI-101-X	Summer 2019	3.67	Fair
ATKI-101-X	Summer 2020	4.00	Good
ATKI-102-X	Summer 2009	5.00	Good
ATKI-102-X	Summer 2010	4.67	Good
ATKI-102-X	Summer 2011	4.33	Good
ATKI-102-X	Summer 2012	4.67	Good
ATKI-102-X	Summer 2013	4.67	Good
ATKI-102-X	Summer 2014	4.00	Good
ATKI-102-X	Summer 2015	3.67	Fair
ATKI-102-X	Summer 2016	3.33	Fair
ATKI-102-X	Summer 2017	3.67	Fair
ATKI-102-X	Summer 2018	3.67	Fair
ATKI-102-X	Summer 2019	3.67	Fair
ATKI-102-X	Summer 2020	3.67	Fair
ATKI-003-X	Summer 2009	4	Good
ATKI-003-X	Summer 2010	3.67	Fair
ATKI-003-X	Summer 2011	3.67	Fair
ATKI-003-X	Summer 2012	3.00	Fair
ATKI-003-X	Summer 2013	3.67	Fair
ATKI-003-X	Summer 2014	3.00	Fair
ATKI-003-X	Summer 2015	2.67	Poor
ATKI-003-X	Summer 2016	3.67	Fair
ATKI-003-X	Summer 2017	2.33	Poor
ATKI-003-X	Summer 2018	3.33	Fair
ATKI-003-X	Summer 2019	3.33	Fair
ATKI-003-X	Summer 2020	3.67	Fair
LWIN-108-X	Summer 2009	4.67	Good
LWIN-108-X	Summer 2010	4.33	Good
LWIN-108-X	Summer 2011	4.33	Good
LWIN-108-X	Summer 2012	4.33	Good
LWIN-108-X	Summer 2013	4.67	Good
LWIN-108-X	Summer 2014	4.33	Good
LWIN-108-X	Summer 2015	4.33	Good
LWIN-108-X	Summer 2016	4.33	Good
LWIN-108-X	Summer 2017	4.67	Good
LWIN-108-X	Summer 2018	4.00	Good
LWIN-108-X	Summer 2019	4.33	Good
LWIN-108-X	Summer 2020	4.33	Good

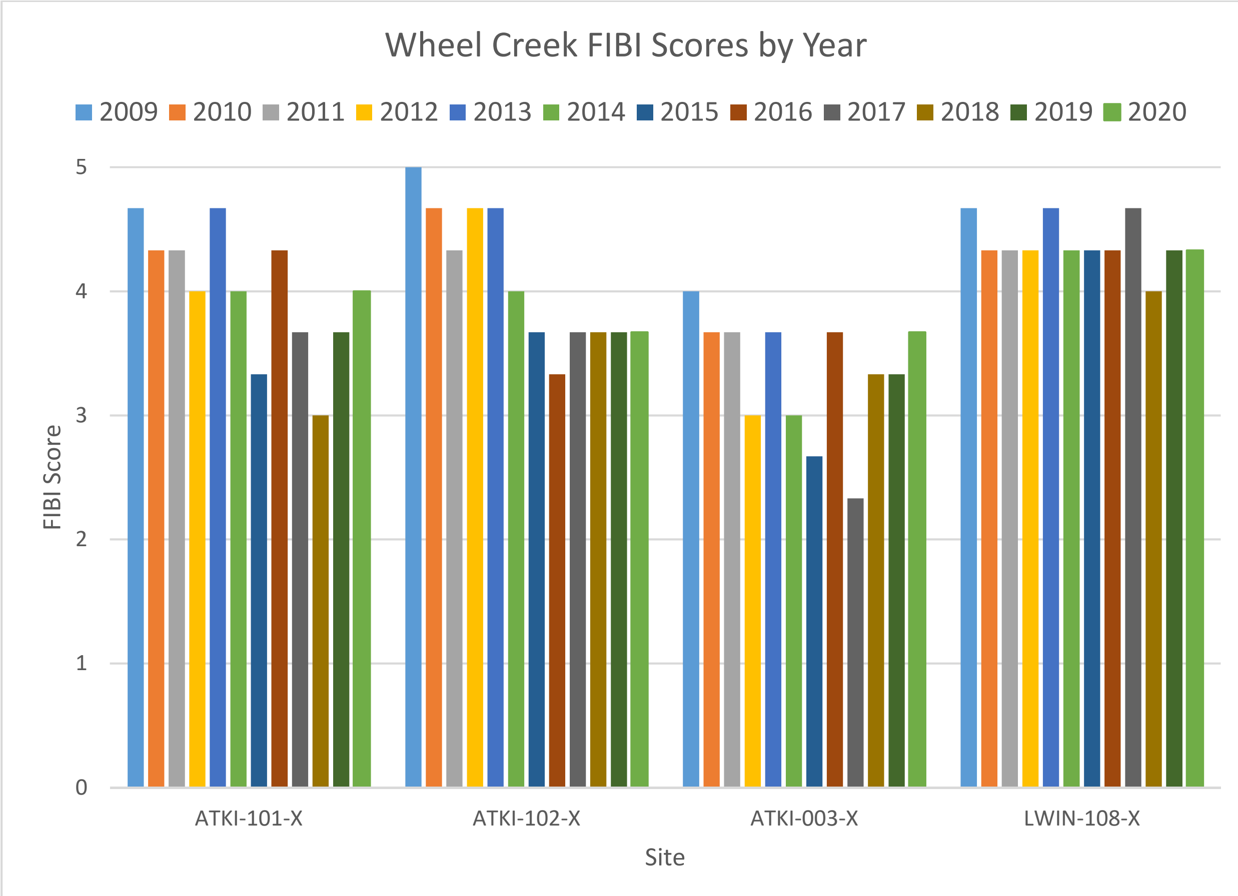

Figure 3 – FIBI Scores by Year

3.5 Herpetofauna

At least one reptile or amphibian species were collected at each of the sites, as presented in Table 14 which represents all species found at each monitoring site across all sampling visits. ATKI-101-X had the highest diversity with five species present at the site. The most widely distributed species was Northern Green Frog, which was present at three of the four Wheel Creek sites. Numbers of stream salamander individuals were low at all sites where they were observed, and consisted entirely of the most pollution-tolerant species the Northern Two-lined Salamander.

Table 14 – Cumulative Herpetofauna Presence at Wheel Creek Sites

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
American Toad	*Anaxyrus americanus*	X			
Northern Green Frog	*Lithobates clamitans melanota*	X	X	X	
Pickerel Frog	*Lithobates palustris*	X			X
American Bullfrog	*Lithobates catesbeianus*			X	
Northern Watersnake	*Nerodia sipedon*	X			
Eastern Milk Snake	*Lampropeltis triangulum*			X	
Queen Snake	*Regina septemvittata*				X
Stream Salamanders					
Northern Two-lined Salamander	*Eurycea bislineata*	X			X

The low density of stream salamanders at all sites is likely due to a combination of habitat degradation and water quality impairment. There was very little suitable stream salamander habitat present at ATKI-102-X and ATKI-003-X during the first visit for the field crew to search. Stream salamanders generally prefer large cover objects over loose cobble and gravel, creating a moist microclimate and many interstices for shelter and foraging. Water quality may be influencing the distribution of stream salamanders in the Wheel Creek watershed. Measured specific conductivity was high at all four sites, ranging from 394 to 502 µS/cm. Stream salamanders breathe through their skins, and because of their highly permeable skin are particularly sensitive to water quality impairments. The high conductivity values suggest that salamanders would experience osmotic difficulties in these conditions.

3.6 Freshwater Mussels

No freshwater mussels were observed at any Wheel Creek site during 2020 field visits. The lack of freshwater mussels at these sites is likely due to a combination of habitat degradation and water quality impairment. Freshwater mussels are relatively sessile organisms which live partially embedded within the stream substrates. The flashy hydrology characteristic of urban streams like Wheel Creek create habitat conditions unsuitable for freshwater mussels. Also, it is likely that water quality conditions in urban streams are outside the range of tolerance of these sensitive organisms.

3.7 Crayfish

Crayfish were observed at each of the four Wheel Creek sites. *Faxonius virilis*, a non-native species, was the only crayfish species observed at each of these sites. Crayfish burrows were not observed at any of the Wheel Creek sites. The lack of native crayfish is most likely due to competition with non-native crayfish. In the Patapsco River watershed, *Faxonius virilis* has displaced the native *Faxonius limosus* from the entire watershed (Kilian et al. 2010). It is likely that a similar species displacement has occurred in the Winters Run watershed. Water quality conditions may also be impacting crayfish, but currently the water quality requirements for crayfish in Maryland are poorly understood.

3.8 Invasive Plant Species

Invasive plant species were present at each of the four Wheel Creek sites. Table 15 presents all invasive species found at each monitoring site across all sampling visits. ATKI-003-X has the most invasive plant species with six, and ATKI-101-X and ATKI-102-X had the second most with five species observed. Mulitflora rose was the most widely distributed invasive plant, found at each of the four sites.

Table 15 – Cumulative Invasive Plant Species Presence at Wheel Creek Sites

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Japanese barberry	*Berberis thunbergii*	X	X	X	
Oriental bittersweet	*Celastrus orbiculatus*	X	X	X	
Japanese stiltgrass	*Microstegium vimineum*	X		X	
Multiflora rose	*Rosa multiflora*	X	X	X	X
Wineberry	*Rubus phoenicolasius*	X			
Mile-a-minute	*Persicaria perfoilata*		X	X	
Privet	*Ligustrum sp.*		X	X	

4. Conclusions

Ecological condition at the three treatment sites in Wheel Creek vary over time throughout the twelve years of data collection with no apparent pattern. BIBI scores at all four sites have remained in the 'Very Poor' or 'Poor' categories, varying slightly from year to year. FIBI scores at the three Wheel Creek treatment sites also vary some over time, but generally in the 'Fair' category. The urban control site, LWIN-108-X, has had FIBI scores in the 'Good' category that varied less than the Wheel Creek sites over the twelve years of record. Looking at the pre- and post-restoration periods, there is no discernable ecological lift in the IBI scores. The ecological condition of Wheel Creek, especially the benthic macroinvertebrate community, continues in a degraded condition similar to other post-restoration urban streams in central Maryland (Hilderbrand et al 2019; Southerland et al 2018).

A comprehensive analysis of data collected at Wheel Creek project sites will occur at the end of 2024. This larger analysis will integrate all ecological, habitat, and water quality data to try to identify correlations in the data set that would help understand what is affecting ecological condition in the Wheel Creek watershed. Analysis will focus not only on the IBI scores, but on individual metrics and species-level response over time to try and highlight changes, if any exist, in the post-restoration data.

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Appendix A: Physical Habitat Data

Project Name: Wheel Creek Biological Monitoring
Project Number: 161602035.06
Prepared by: SLF
Prepared date: 10/8/2020

PHI_Piedmont_v3_WheelCrk_2020.xlsx

		RAW DATA								SCALED METRICS								SCORES	
Site	Subshed Area (ac)*	Instream Habitat	Epifaunal Substrate	Embeddedness	Percent Shading	# Woody Debris/ Rootwads	Riffle Quality	Bank Stability	Remoteness Score	Instream Habitat	Epifaunal Substrate	Embeddedness	Percent Shading	# Woody Debris/ Rootwads	Riffle Quality	Bank Stability	Remoteness	PHI	PHI Rating
ATKI-101-X-2020	393.08	13	12	25	80	2	14	17	8	74.96	64.71	83.33	72.07	16.67	92.47	95.05	48.50	68.5	Partially Degraded
ATKI-102-X-2020	146.07	13	12	25	50	2	11	20	7	79.18	64.71	83.33	43.09	16.67	82.47	100.00	43.52	64.1	Degraded
ATKI-003-X-2020	105.03	10	12	60	30	3	9	16	6	61.54	64.71	44.44	26.41	25.00	74.04	91.22	37.82	53.1	Degraded
LWIN-108-X-2020	411.86	14	9	45	85	7	10	6	9	81.11	47.06	61.11	77.06	58.33	71.86	44.70	54.03	61.9	Degraded

Score	Narrative Rating
81-100	Minimally Degraded
66.0-80.9	Partially Degraded
51.0-65.9	Degraded
0-50.9	Severely Degraded

Appendix B: Benthic Macroinvertebrate Data

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF
Prepared date: 10/8/2020
Checked by: AJB
Checked date: 10/28/2020

2020_WheelCrk_Piedmont.xlsx
Version:

Metric	ATKI-101-X-2020	ATKI-102-X-2020	ATKI-003-X-2020	LWIN-108-X-2020
Raw Scores				
Total Number of Taxa	19	19	18	23
Number of EPT Taxa	5	5	5	6
Number of Ephemeroptera Taxa	1	2	1	1
Percent Intolerant Urban	3.79	0.00	2.17	5.26
Percent Chironomidae	60	64	86.23	84.21
Percent Clingers	0.00	0.00	15.22	25.56
BIBI Scores				
Total Number of Taxa	3	3	3	3
Number of EPT Taxa	3	3	3	3
Number of Ephemeroptera Taxa	1	3	1	1
Percent Intolerant Urban	1	1	1	1
Percent Chironomidae	3	1	1	1
Percent Clingers	1	1	1	1
BIBI Score	***2.00***	***2.00***	***1.67***	***1.67***
Narrative Rating	***Poor***	***Poor***	***Very Poor***	***Very Poor***

Piedmont		Score	
Metric	**5**	**3**	**1**
Total Number of Taxa	≥25	15 - 24	<15
Number of EPT Taxa	≥11	5 - 10	<5
Number Ephemeroptera Taxa	≥4	2 - 3	<2
Percent Intolerant Urban	≥51	12 - 50	<12
Percent Chironomidae	<24	24 - 63	>63
Percent Clingers	≥74	31 - 73	<31

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 10/8/2020 Checked date: 10/28/2020

2020_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -101-X-2020

KCI TECHNOLOGIES

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Oligochaeta	Haplotaxida	Naididae	not identified	Naididae	U	4	Collector	bu	8.5
Insecta	Coleoptera	Psephenidae	Psephenus	Psephenus	I	1	Scraper	cn	4.4
Insecta	Diptera	Chironomidae	Cardiocladius	Cardiocladius	I	15	Predator	bu, cn	10
Insecta	Diptera	Chironomidae	Corynoneura	Corynoneura	I	5	Collector	sp	4.1
Insecta	Diptera	Chironomidae	Cricotopus	Cricotopus	I/P	6	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Diamesa	Diamesa	I	1	Collector	sp	8.5
Insecta	Diptera	Chironomidae	Neozavrelia	Neozavrelia	I	6	0	0	na
Insecta	Diptera	Chironomidae	not identified	Tanytarsini	P	1	Collector	0	3.5
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I	5	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	I	23	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	6	Filterer	cn	7.2
Insecta	Diptera	Chironomidae	Thienemanniella	Thienemanniella	I	5	Collector	sp	5.1
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia	I/P	6	Collector	sp	5.1
Insecta	Diptera	Simuliidae	Simulium	Simulium	I	6	Filterer	cn	5.7
Insecta	Ephemeroptera	Baetidae	Baetis	Baetis	I	23	Collector	sw, cb, cn	3.9
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	1	Filterer	cn	6.5
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	2	Filterer	cn	7.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	1	Filterer	cn	4.4
Insecta	Trichoptera	Philopotamidae	Dolophilodes	Dolophilodes	I	5	Filterer	cn	1.7
Turbellaria	Tricladida	Dugesiidae	Girardia	Girardia	U	10	Predator	sp	9.3

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 10/8/2020 Checked date: 10/28/2020

2020_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -102-X-2020

KCI TECHNOLOGIES

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Oligochaeta	Haplotaxida	Naididae	not identified	Naididae	U	14	Collector	bu	8.5
Oligochaeta	Tubificida	Tubificidae	not identified	Tubificidae	U	2	Collector	cn	8.4
Insecta	Coleoptera	Elmidae	Stenelmis	Stenelmis	I/A	14	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	Cricotopus	Cricotopus	I	10	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Diamesa	Diamesa	I	9	Collector	sp	8.5
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I/P	17	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	I/P	38	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	I	2	Collector	sp	7.7
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	1	Filterer	cn	7.2
Insecta	Diptera	Chironomidae	Tanytarsus	Tanytarsus	I	1	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Thienemannimyia gro	Thienemannimyia Group	I	1	Predator	sp	8.2
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia	I	15	Collector	sp	5.1
Insecta	Diptera	Tipulidae	Limonia	Limonia	I	2	Shredder	bu, sp	4.8
Insecta	Ephemeroptera	Baetidae	Acentrella	Acentrella	I	1	Collector	sw, cn	4.9
Insecta	Ephemeroptera	Baetidae	Baetis	Baetis	I	4	Collector	sw, cb, cn	3.9
Insecta	Odonata	Aeshnidae	Boyeria	Boyeria	I	1	Predator	cb, sp	6.3
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	7	Filterer	cn	6.5
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	7	Filterer	cn	7.5
Insecta	Trichoptera	Hydroptilidae	Hydroptila	Hydroptila	I	1	Scraper	cn	6

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 10/8/2020 Checked date: 10/28/2020

2020_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -003-X-2020

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Ephemeroptera	Baetidae	Baetis	Baetis	I	1	Collector	sw, cb, cn	3.9
Insecta	Trichoptera	Hydropsychidae	Ceratopsyche	Ceratopsyche	I	1	Collector	0	na
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	4	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	1	Filterer	cn	4.4
Insecta	Diptera	Chironomidae	Diamesa	Diamesa	I	4	Collector	sp	8.5
Gastropoda	Basommatophora	Ancylidae	Ferrissia	Ferrissia	U	2	Scraper	cb	7
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	2	Filterer	cn	7.5
Insecta	Diptera	Chironomidae	Micropsectra	Micropsectra	I	3	Collector	cb, sp	2.1
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I	5	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	I/P	81	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	I	2	Collector	sp	7.7
Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum	I	2	Shredder	cb, cn	6.3
Insecta	Coleoptera	Psephenidae	Psephenus	Psephenus	I	1	Scraper	cn	4.4
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	2	Filterer	cn	7.2
Insecta	Coleoptera	Elmidae	Stenelmis	Stenelmis	I	7	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	Tanytarsus	Tanytarsus	I	1	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Thienemannimyia gro	Thienemannimyia Group	I/P	3	Predator	sp	8.2
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia	I/P	16	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 10/8/2020 Checked date: 10/28/2020

2020_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -108-X-2020

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Oligochaeta	Haplotaxida	Naididae	not identified	Naididae	U	1	Collector	bu	8.5
Insecta	Diptera	Ceratopogonidae	Atrichopogon	Atrichopogon	I	1	Predator	0	3.6
Insecta	Diptera	Chironomidae	Brillia	Brillia	I	10	Shredder	bu, sp	7.4
Insecta	Diptera	Chironomidae	Cricotopus	Cricotopus	I	10	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Diamesa	Diamesa	I	6	Collector	sp	8.5
Insecta	Diptera	Chironomidae	Eukiefferiella	Eukiefferiella	I	5	Collector	sp	6.1
Insecta	Diptera	Chironomidae	Orthocladius	Orthocladius	I/P	31	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	I	15	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	I	1	Collector	sp	7.7
Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum	I	3	Shredder	cb, cn	6.3
Insecta	Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	I	5	Filterer	cn	7.2
Insecta	Diptera	Chironomidae	Thienemanniella	Thienemanniella	I	10	Collector	sp	5.1
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia	I/P	16	Collector	sp	5.1
Insecta	Diptera	Empididae	not identified	Empididae	P	1	Predator	sp, bu	7.5
Insecta	Diptera	Simuliidae	Simulium	Simulium	I	3	Filterer	cn	5.7
Insecta	Diptera	Tipulidae	Dicranota	Dicranota	I	1	Predator	sp, bu	1.1
Insecta	Ephemeroptera	Baetidae	Baetis	Baetis	I	2	Collector	sw, cb, cn	3.9
Insecta	Plecoptera	Nemouridae	Amphinemura	Amphinemura	I	4	Shredder	sp, cn	3
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	I	3	Filterer	cn	6.5
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	I	1	Filterer	cn	7.5
Insecta	Trichoptera	Philopotamidae	Chimarra	Chimarra	I	1	Filterer	cn	4.4
Insecta	Trichoptera	Philopotamidae	Dolophilodes	Dolophilodes	I	2	Filterer	cn	1.7
Gastropoda	Basommatophora	Ancylidae	Ferrissia	Ferrissia	U	1	Scraper	cb	7

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Appendix C: Fish Data

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF
Prepared date: 10/12/2020

Checked by: AJB
Checked date: 12/18/2020

FIBI_WheelCrk_2020.xlsx

KCI TECHNOLOGIES

Metric	ATKI-101-X-2020	ATKI-102-X-2020	ATKI-003-X-2020	LWIN-108-X-2020
Raw Scores				
Abundance per square meter	2.55	9.57	2.40	1.19
Adjusted Number of Benthic species	2.26	2.89	6.00	2.20
% Tolerant	47.55%	89.35%	97.67%	31.54%
% Generalist, Omnivores, Invertivores	62.10%	89.35%	97.67%	47.71%
Biomass per square meter	8.10	20.25	9.53	6.17
% Lithophilic Spawners	56.20%	34.86%	48.06%	72.51%
FIBI Scores				
Abundance per square meter	5	5	5	3
Adjusted Number of Benthic species	5	5	5	5
% Tolerant	3	1	1	5
% Generalist, Omnivores, Invertivores	5	3	3	5
Biomass per square meter	3	5	5	3
% Lithophilic Spawners	3	3	3	5
FIBI Score	***4.00***	***3.67***	***3.67***	***4.33***
Narrative Rating	***Good***	***Fair***	***Fair***	***Good***

Eastern Piedmont	**Score**		
Metric	**5**	**3**	**1**
Abundance per square meter	≥ 1.25	0.25 – 1.24	< 0.25
Adjusted Number of Benthic species	≥ 0.26	0.09 – 0.25	< 0.09
% Tolerant	≤ 45	46 – 68	> 68
% Generalist, Omnivores, Invertivores	≤ 80	81 - 99	100
Biomass per square meter	≥ 8.6	4.0 – 8.5	< 4.0
% Lithophilic Spawners	≥ 61	32 - 60	< 32

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 10/12/2020 Checked date: 12/18/2020

FIBI_WheelCrk_2020.xlsx
Site Name: ATKI-101-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Bluntnose Minnow	*Pimephales notatus*	82	OTHRCYPR	T	OM	N	NOTYPE	82	82	0	0	0.30	
Fallfish	*Semotilus corporalis*	4	OTHRCYPR	I	GE	Y	NOTYPE	0	4	4	0	0.01	
Blue Ridge Sculpin	*Cottus caeruleomentum*	263	SCULPIN	I	IS	Y	B	0	0	263	1	0.97	
Fathead minnow	*Pimephales promelas*	4	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	4	0	0	0.01	
Blacknose Dace	*Rhinichthys atratulus*	133	OTHRCYPR	T	OM	N	NOTYPE	133	133	0	0	0.49	
Tessellated Darter	*Etheostoma olmstedi*	3	DARTER	T	IV	N	B	3	3	0	1	0.01	
Creek Chub	*Semotilus atromaculatus*	84	OTHRCYPR	T	GE	Y	NOTYPE	84	84	84	0	0.31	
Common Shiner	*Luxilus cornutus*	21	SHINER	I	OM	Y	NOTYPE	0	21	21	0	0.08	
Redbreast Sunfish	*Lepomis auritus*	23	SUNFISH	NOTYPE	GE	N	NOTYPE	0	23	0	0	0.08	
Bluegill	*Lepomis macrochirus*	7	SUNFISH	T	IV	N	NOTYPE	7	7	0	0	0.03	
White Sucker	*Catostomus commersonii*	6	SUCKER	T	OM	Y	NOTYPE	6	6	6	0	0.02	
Rosyside Dace	*Clinostomus funduloides*	12	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	12	12	0	0.04	
Eastern Mosquitofish	*Gambusia holbrooki*	36	NOTYPE	NOTYPE	IV	N	NOTYPE	0	36	0	0	0.13	
Pumpkinseed	*Lepomis gibbosus*	15	SUNFISH	T	IV	N	NOTYPE	15	15	0	0	0.06	
Longnose Dace	*Rhinichthys cataractae*	1	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	1	0	0	0.00	
	Total Count	*694*						*47.55%*	*62.10%*	*56.20%*	*2.26*	2.55	*8.10*
	Total Biomass (g)	*2203*											

Project Name: Wheel Creek Monitoring 2020
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 10/12/2020 Checked date: 12/18/2020

FIBI_WheelCrk_2020.xlsx

Site Name: ATKI-102-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	783	OTHRCYPR	T	OM	N	NOTYPE	783	783	0	0	6.23	
Creek Chub	*Semotilus atromaculatus*	291	OTHRCYPR	T	GE	Y	NOTYPE	291	291	291	0	2.32	
Blue Ridge Sculpin	*Cottus caeruleomentum*	128	SCULPIN	I	IS	Y	B	0	0	128	1	1.02	
	Total Count	*1202*						*89.35%*	*89.35%*	*34.86%*	*2.89*	9.57	*20.25*
	Total Biomass (g)	*2544*											

Project Name:	Wheel Creek Monitoring 2020		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	AJB
Prepared date:	10/12/2020	Checked date:	12/18/2020

FIBI_WheelCrk_2020.xlsx

Site Name: ATKI-003-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	201	OTHRCYPR	T	OM	N	NOTYPE	201	201	0	0	1.25	
Creek Chub	*Semotilus atromaculatus*	177	OTHRCYPR	T	GE	Y	NOTYPE	177	177	177	0	1.10	
Blue Ridge Sculpin	*Cottus caeruleomentum*	9	SCULPIN	I	IS	Y	B	0	0	9	1	0.06	
	Total Count	*387*						*97.67%*	*97.67%*	*48.06%*	*6.00*	2.40	*9.53*
	Total Biomass (g)	*1536*											

Project Name:	Wheel Creek Monitoring 2020
Project Number:	161602035.06
Prepared by:	SLF
Prepared date:	10/12/2020

Checked by: AJB
Checked date: 12/18/2020

FIBI_WheelCrk_2020.xlsx

Site Name: LWIN-108-X-2020

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blue Ridge Sculpin	*Cottus caeruleomentum*	194	SCULPIN	I	IS	Y	B	0	0	194	1	0.62	
Creek Chub	*Semotilus atromaculatus*	29	OTHRCYPR	T	GE	Y	NOTYPE	29	29	29	0	0.09	
Blacknose Dace	*Rhinichthys atratulus*	63	OTHRCYPR	T	OM	N	NOTYPE	63	63	0	0	0.20	
Rosyside Dace	*Clinostomus funduloides*	28	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	28	28	0	0.09	
White Sucker	*Catostomus commersonii*	9	SUCKER	T	OM	Y	NOTYPE	9	9	9	0	0.03	
Northern Hogsucker	*Hypentelium nigricans*	5	SUCKER	I	IV	Y	R	0	5	5	0	0.02	
Margined Madtom	*Noturus insignis*	5	MADTOM	I	IV	N	B	0	5	0	1	0.02	
American Eel	*Anguilla rostrata*	8	NOTYPE	NOTYPE	GE	N	NOTYPE	0	8	0	0	0.03	
Longnose Dace	*Rhinichthys cataractae*	10	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	10	0	0	0.03	
Bluntnose Minnow	*Pimephales notatus*	16	OTHRCYPR	T	OM	N	NOTYPE	16	16	0	0	0.05	
Common Shiner	*Luxilus cornutus*	4	SHINER	I	OM	Y	NOTYPE	0	4	4	0	0.01	
	Total Count	*371*						*31.54%*	*47.71%*	*72.51%*	*2.20*	1.19	*6.17*
	Total Biomass (g)	*1921*											

Appendix D: Supplemental Flora/Fauana Data

ATKI-101-X

Invasive Plants	Relative Abundance
Japanese barberry	Present
Japanese stiltgrass	Extensive
Wineberry	Present
Multiflora rose	Present
Oriental bittersweet	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog
Northern water snake
Pickerel frog
American toad

Crayfish
Faxonius virilis

ATKI-102-X

Invasive Plants	Relative Abundance
Japanese barberry	Present
Oriental bittersweet	Present
Multiflora rose	Present
Mile-a-minute	Present
Privet	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog

Crayfish
Faxonius virilis

ATKI-003-X

Invasive Plants	Relative Abundance
Japanese barberry	Present
Oriental bittersweet	Present
Japanese stiltgrass	Present
Multiflora rose	Present
Mile-a-minute	Present
Privet	Present

Stream Salamanders
None Observed

Other Herpetofauna
Northern green frog
American bullfrog
Eastern milksnake

Crayfish
Faxonius virilis

LWIN-108-X

Invasive Plants	Relative Abundance
Multiflora rose	Present

Stream Salamanders
None Observed

Other Herpetofauna
Pickerel frog
Queen snake

Crayfish
Faxonius virilis

WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 4
FINAL REPORT

VERSAR

Your Needs. Our Mission.

November 4, 2020

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WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 4 FINAL REPORT

Prepared for:

Harford County
Department of Public Works
Division of Highways and Water Resources
212 South Bond Street
Bel Air, Maryland 21014

Prepared by

Versar, Inc.
9200 Rumsey Road, Suite 1
Columbia, Maryland 21045

November 4, 2020

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1.0 INTRODUCTION

Harford County Department of Public Works (DPW) has completed the restoration of the Wheel Creek watershed, which is located in the Bush River Basin in the central portion of Harford County near Bel Air (Figure 1-1). The restoration is the result of previous planning efforts including the Bush River Watershed Restoration Strategy (WRAS), the Bush River Watershed Management Plan in 2003, and the Wheel Creek Watershed Assessment completed in 2008.

Restoration efforts in this watershed began in September 2012 with the retrofit of a stormwater management facility (Pond A) located at the Gardens of Bel Air, and construction was completed in December of 2012. A second project, the Calvert's Walk stream restoration project, began in January of 2013 and was completed that April. In 2015, two more stormwater management facilities were retrofitted, Pond C in August and Pond D in December. The final phase of implementation was completed in March of 2017. These projects included the Lower Wheel Creek stream restoration and the retrofit of the final stormwater management facility (Pond E).

As part of implementing the restoration efforts, the County was awarded funds from a Local Government Implementation Grant through the Chesapeake and Atlantic Coastal Bays 2010 and 2016 Trust Funds. Under the grant proposal, the County planned to implement a total of four stormwater retrofits and five stream restoration projects to improve water quality, decrease stormwater discharges, and improve instream habitat.

Beginning in 2009, the County initiated monitoring to demonstrate measurable reductions of sediment and nutrients, improvement in physical stability and instream habitat, and improvement in fish and benthic macroinvertebrates communities. As a collaborative monitoring effort, Harford County DPW, Maryland Department of Natural Resources (DNR), the United States Geologic Survey (USGS), and two consulting firms (KCI Technologies and Versar, Inc.) have performed select data collection activities. The study design was developed to compare Pre-Construction conditions (i.e., baseline conditions) to future Post-Construction restoration conditions. This report focuses on seven years of geomorphic monitoring, conducted by KCI and Versar. Data generated by other project partners includes:

- USGS – flow gaging at the downstream end of Wheel Creek (5-minute interval discharge record);
- Maryland DNR (Up to July 2016)/Versar (July 2016 to present) – flow gaging at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (5-minute interval discharge record);
- KCI – Biological and physical habitat data; and
- Versar – Storm runoff water chemistry and water quality monitoring including nutrient and sediment data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (pollutant loads for the measured parameters for each sampled event)

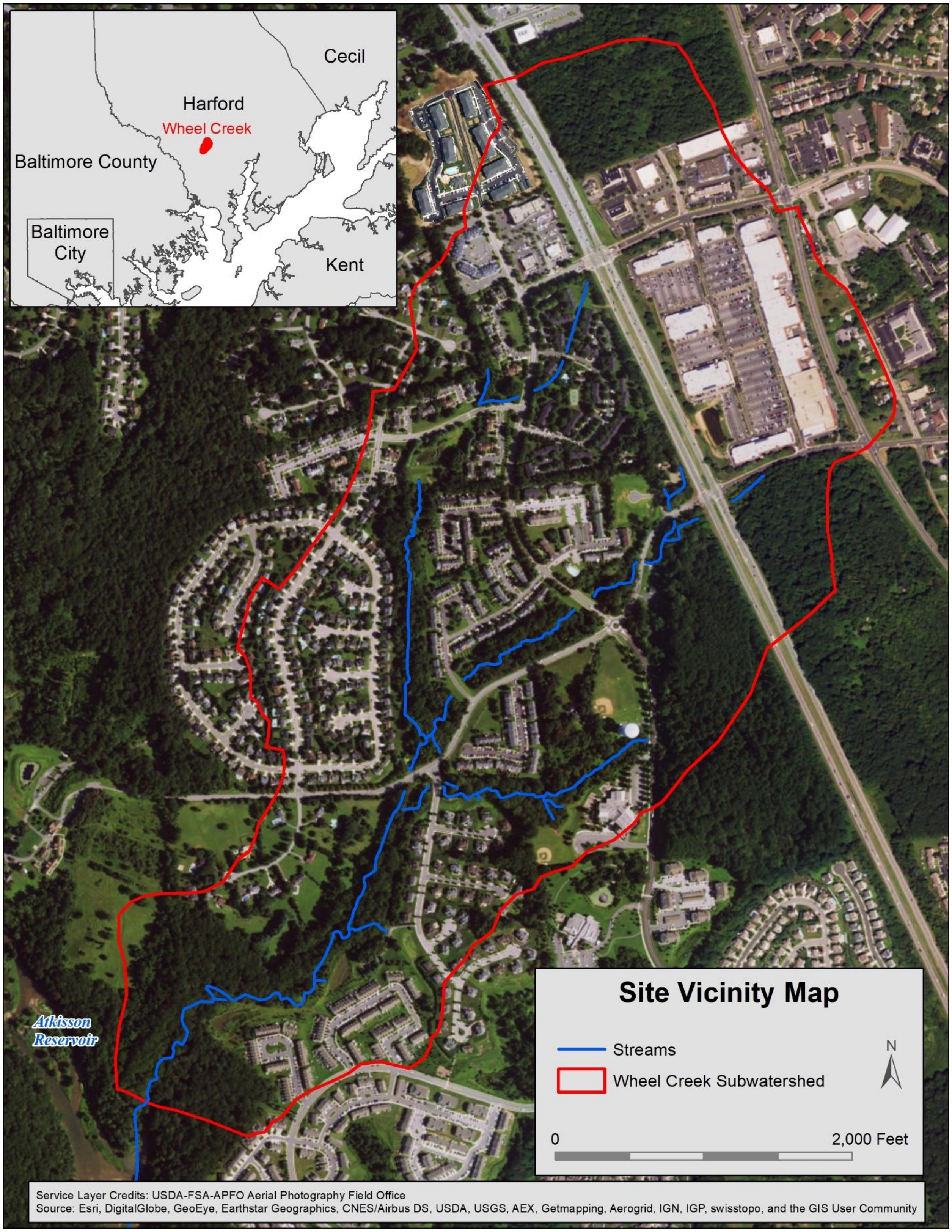

Figure 1-1. Site vicinity map

- Harford County DPW (Up to March 2019)/Versar (April 2019 to present) – Baseflow nutrient and total suspended solids data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court.

Assessment and monitoring of the physical geomorphologic conditions was initially performed by KCI in 2010 (Pre-Restoration Year 1) to evaluate baseline conditions and was continued by Versar in 2012 (Pre-Restoration Year 2), 2013 (Pre-Restoration Year 3), 2015 (Pre-Restoration Year 4), 2017 (Post-Restoration Year 1), 2018 (Post-Restoration Year 2), 2019 (Post-Restoration Year 3), and 2020 (Post-Restoration Year 4). The geomorphic monitoring program was designed to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. The geomorphic monitoring includes surveying and analyzing monumented cross-sections and longitudinal profiles at four (4) reaches (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 4), monitoring bankpins and scour chains (Pre-Restoration Year 1 through 4 only), mapping substrate facies (Pre-Restoration Year 1 only), and evaluating substrate particle size distribution (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 4). The methods evaluate bed and bank stability, channel profile, and bed features. For a complete description of the Year 1 Study see *Wheel Creek Watershed Restoration Project, Pre-Construction Monitoring, Baseline Conditions, 2009-2011* (KCI, 2012). For a complete description of the Year 2, Year 3, and Year 4 Studies see *Wheel Creek Geomorphic Assessment Year 2* (Versar, 2013), *Wheel Creek Geomorphic Assessment Year 3* (Versar, 2014) and *Wheel Creek Geomorphic Assessment Year 4* (Versar, 2015). For a complete description of the Post-Restoration Year 1 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 1 Final Report* (Versar, 2017), Year 2 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 2 Final Report* (Versar, 2018), and Year 3 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 3 Final Report* (Versar, 2019). This report focuses on continued geomorphic monitoring, including a comparison of data collected during Pre-Restoration Years 1, 2, 3, 4, and Post-Restoration Years 1, 2, 3, and 4.

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2.0 METHODOLOGIES

2.1 GEOMORPHIC ASSESSMENT

The primary goal of the geomorphic monitoring is to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. Assessment techniques include a survey of permanently-monumented channel cross-sections, a longitudinal profile survey, particle size analysis, substrate facies mapping (Pre-Restoration Year 1 only), and assessment of bank pins and scour chains (Pre-Restoration Years 1 through 4 only). In 2010, four (4) assessment reaches (Figure 2-1) were established by KCI for geomorphic monitoring based on the following treatments:

1. within a stream stabilization reach (WC01);
2. within a stream stabilization reach and downstream of a retrofitted stormwater management facility (WC02);
3. downstream of a retrofitted stormwater management facility (WC03); and
4. a control site with no proposed restoration activities (WC04).

These reaches were re-surveyed by Versar in 2012, 2013, 2015, 2017, 2018, 2019, and 2020 to provide additional monitoring data. Cross-sectional and longitudinal profile surveys were first conducted to establish baseline conditions of channel geometry and slope. Subsequent survey data can be compared to the baseline data to determine whether lateral or vertical migration of the channel is occurring and to document any changes that have occurred in the restored reaches. Bank and bed pins were monitored to determine rates of potential bank and channel bed erosion or aggradation, while scour chains were used to quantify the extent of bed material scouring. The bank and bed pins along with the scour chains have been discontinued from the monitoring following Pre-Restoration Year 4 (2015). Pebble counts were conducted to assess substrate particle size distribution and track changes in channel roughness. Detailed methods are described below.

2.1.1 Longitudinal Profile and Cross-sectional Surveys

KCI installed and surveyed three (3) benchmark monuments at each reach during the initial baseline monitoring effort (2010) to establish consistent survey elevations from year to year, as well as start and end points for each survey reach. Two benchmarks (one concrete monument and one capped iron rebar pin) were placed on either side of the channel, whereby a measuring tape run from the left bank pin to the right bank monument marks the starting point (i.e., station 0+00) in the channel for the longitudinal profile. The concrete monument was set in 2-inch PVC piping to a depth of 30 inches, with a rounded stove bolt set in the concrete to establish the monumented benchmark elevation, which will be used to compare longitudinal profiles over time. A third monument (capped iron rebar) was placed at the upstream end of the reach to mark the end of the survey reach. Versar re-surveyed these benchmarks at WC03 and WC04 during the Post-Restoration Years 1, 2, 3, and 4 efforts to enable overlays between past surveys.

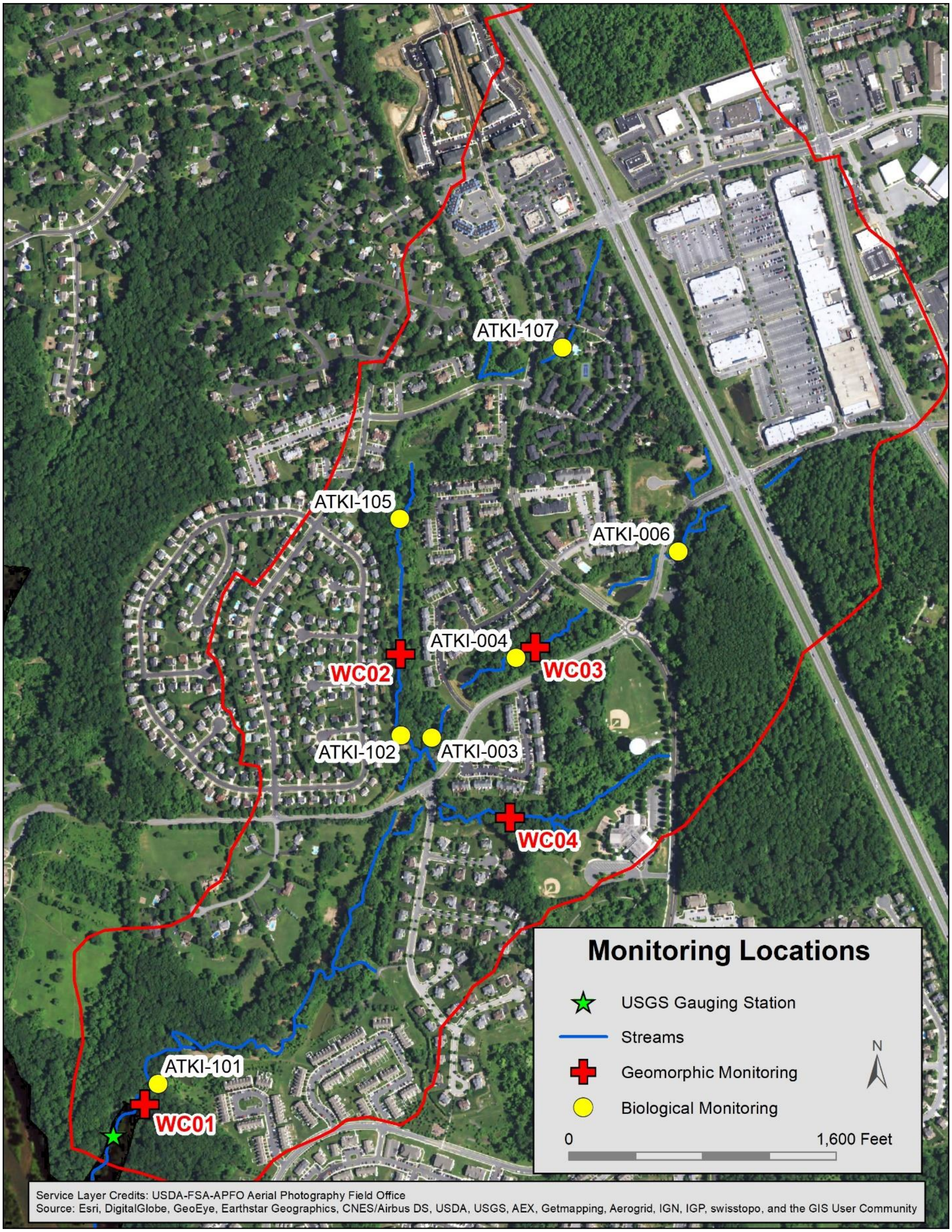

Figure 2-1. Wheel Creek monitoring locations

Versar re-established reaches WC01 and WC02 in 2017 for Post-Restoration Year 1 monitoring. Three (3) benchmark monuments were again installed at both reaches. Two capped iron rebar monuments were installed on each side of the channel to mark the starting point of the new longitudinal profile (i.e., station 0+00). An additional capped iron rebar monument was installed upstream marking the end of the longitudinal profile. These were re-surveyed in 2018, 2019, and 2020.

A longitudinal profile of each reach was surveyed using a laser level, calibrated stadia rod, and 300-foot measuring tape following the procedure outlined in Harrelson et al. (1994). The longitudinal profiles were initially established to encompass a minimum reach length of approximately 20 bankfull widths or 300 feet, measured along the centerline of each bankfull channel. Each reach was started at the top of a feature located at the downstream benchmarks, and finished at the top of a feature at or above the upstream benchmark. Each reach included a survey of breakpoints in and between bed features and delineation of riffle, run, pool, and glide features. A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. At each site where instream restoration activities did not occur (WC03 and WC04), the plotted Post-Restoration Years 1 through 4 longitudinal profiles were overlaid with the plots from Pre-Restoration Years 1 through 4. These plots enable comparisons between years and are used to track changes that occur in the bed sequences and channel slopes. At the two sites where instream restoration occurred (reaches WC01 and WC02), the plotted profiles from Pre-Restoration Years 1 through 4 were overlaid and the Post-Restoration Years 1 through 4 plotted profiles were compared.

In order to establish locations where fluvial geomorphic characteristics of the channel could be measured and compared from one year to the next for assessing bed and bank stability, KCI established permanent cross-sections at two (2) locations within each monitoring reach during Pre-Restoration Year 1; one located on a meander bend and one within a riffle feature. KCI established monuments (one concrete and one capped iron rebar) on either side of the channel to mark the cross-section locations and benchmark elevations. Concrete monuments were set in 2-inch PVC piping to a depth of 30 inches, with a rounded metal stove bolt set in the concrete to mark the monumented elevation. Wherever possible, the monuments were set flush to the ground surface for safety concerns, and the location of each monument was recorded using a GPS unit capable of sub-meter accuracy.

Permanent cross-sections were established in 2010 and surveyed during Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 4 within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at several stations due to channel migration over time or as a result of re-installing a cross-section when instream restoration has occurred. Cross-sections located in reaches WC01 and WC02 were re-established with new benchmarks in Post-Restoration Year 1 (2017). Due to ongoing restoration construction activities, the WC01 left end pin at Cross-section 2 had to be reinstalled in 2018, as it could not be located during the Post-Restoration Year 2 survey. Reaches WC03 and WC04 were still monumented to the original benchmarks installed in Pre-Restoration Year 1 (2010) since no instream restoration occurred at those locations. However, the WC03 right end pin at Cross-section 2 had to be reinstalled in 2019, as it had eroded away and fallen into the stream channel during the Post-Restoration Year 3 survey. The same methods were used to establish the new cross-sections in these reaches, although the corresponding station on the longitudinal profile will not be comparable to previous years of Pre-Restoration surveying.

Table 2-1. Cross-sectional survey locations

Reach	WC01*		WC02*		WC03		WC04	
Profile Station (Pre-Year 1)	2+30	2+95	1+37	3+24	1+55	2+07	1+08	1+68
Profile Station (Pre-Year 2)	2+30	2+95	1+38	3+24	1+57	2+08	1+08	1+68
Profile Station (Pre-Year 3)	2+29	2+95	1+38	3+25	1+56	2+12	1+08	1+68
Profile Station (Pre-Year 4)	2+29	2+95	1+38	3+24	1+55	2+07	1+08	1+68
Profile Station (Post-Year 1)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 2)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 3)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 4)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Feature	Riffle	Meander/ Pool	Riffle	Pool	Riffle	Meander/ Run	Meander/ Pool	Riffle

*Cross-sections re-established during Post-Restoration Year 1

During Post-Restoration Year 4, Versar resurveyed the cross-sections using a laser level, calibrated stadia rod, and measuring tape following the procedure outlined in Harrelson et al. (1994). The cross-sectional surveys captured features of the floodplain, monuments, and all pertinent channel features including:

- Top of bank
- Bankfull elevation
- Edge of water
- Limits of point and instream depositional features
- Thalweg
- Floodprone elevation

Longitudinal profile and cross-sectional data were entered into *The Reference Reach Spreadsheet* version 4.3L (ODNR, 2012) for data analysis and graphical interpretation. Profile and cross-sectional data collected in 2010, 2012, 2013, 2015, 2017, 2018, 2019, and 2020 provide eight years of data to which subsequent monitoring events will be overlaid and/or compared to assess changes in channel dimension, pattern, and profile.

For the purpose of this report, bankfull elevations were selected based upon bankfull indicators observed in the field. Channel geometry and cross-sectional areas were calculated using *The Reference Reach Spreadsheet* (ODNR, 2012). Because bankfull indicators are not always easily discernible from year to year and best professional judgment is often required to determine bankfull elevations, top of bank features were also measured. Top of low bank cross-sectional areas were also calculated and can be utilized for future monitoring events to generate hydraulic geometry values that are more directly comparable between each monitoring effort.

2.1.2 Particle Size Analysis

Channel substrate composition (e.g., gravel, sand, silt) is an important aspect of a stream's biological and geomorphic character. The substrate size and complexity affects the stream's available habitat for benthic fauna and determines a channel's roughness, which influences the channel flow characteristics. To quantify the distribution of channel substrate particle sizes within the study area, modified Wolman pebble counts (Wolman, 1954; Harrelson et al., 1994) were performed. A total of three (3) pebble counts were conducted within each monitoring reach; one (1) feature-specific pebble count was conducted at each cross-section location within the cross-sectional bed feature (two (2) total within each reach), and one (1) weighted pebble count was conducted throughout the entire reach based on the proportion of bed features (e.g., riffle, run, pool, glide) present within the survey reach. Feature-specific pebble counts were performed via 10 evenly-spaced transects positioned throughout the survey feature, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. The weighted (proportional) pebble count was conducted at 10 transects positioned throughout the entire reach based on the proportion of bed features, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. For both types of counts, particles were chosen without visual bias by reaching forth with an extended finger into the stream bed while looking away and choosing the first particle that comes in contact with the sampler's finger. All particles were then measured across the intermediate axis using a gravelometer and resultant data were entered into *The Reference Reach Spreadsheet* (ODNR, 2012). The results of each weighted pebble count were used to determine the median particle size (i.e., D_{50}) of the specific reach. Additionally, the D_{84} was calculated from the feature pebble counts to determine the particle size that 84 percent of the sample is of the same size or smaller. The D_{84} particles were used in calculating channel velocity and discharge. Results from Versar's Post-Restoration Year 4 evaluations were compared to those found during the previous years of monitoring to evaluate changes in channel substrate composition and stability.

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3.0 RESULTS AND DISCUSSION

3.1 FLUVIAL GEOMORPHIC ASSESSMENT

3.1.1 Longitudinal Profiles and Cross-sectional Surveys

The fourth year of Post-Restoration longitudinal profile and cross-sectional surveys was completed between June 5th and June 17th, 2020. While performing the longitudinal profile, bed features including riffles, runs, pools, glides, bankfull indicators (where readily discernible), and water surface were noted to sufficiently assess conditions. The longitudinal profile data were analyzed to calculate the water surface slope and proportion of bed features for each monitoring reach (Table 3-1). These data will be compared to previous and subsequent annual monitoring data to track potential changes in the overall channel slope. Refer to Appendix A for photographs depicting the overall site conditions during the Post-Restoration Year 4 survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, but only overlain and compared to the Pre-Restoration Years 1, 2, 3, and 4 profiles at WC03 and WC04 (Appendix C) and will be compared to subsequent annual surveyed profiles in order to assess changes occurring in the bed structure. Due to instream restoration activities, WC01 and WC02 Post-Restoration overlays do not share the same monuments as Pre-Restoration. Therefore, separate Post-Restoration overlays were created for these reaches.

Table 3-1. Results of longitudinal profile survey – Post-Restoration Year 4

Reach	Length (ft)	Slope	Proportion of Features			
			Riffle	Run	Pool	Glide
WC01*	490	2.7%	35.6%	17.2%	27.8%	19.4%
WC02*	340	2.2%	49.7%	9.3%	23.6%	17.4%
WC03	308	1.8%	42.6%	7.4%	35.4%	14.6%
WC04	300	3.5%	57.2%	18.3%	16.2%	8.3%

*Profiles re-established during Post-Restoration Year 1

Cross-sectional surveys were analyzed at each of the eight permanent monitoring locations to determine bankfull width, mean depth, width/depth ratio, and overall cross-sectional area during baseline conditions. Since bankfull elevation is based on field indicators and can be somewhat subjective to determine in the field, top-of-bank elevation was also calculated and will be utilized to track changes in the cross-sectional dimensions listed below. Results of the cross-sectional measurements are included in Table 3-2 and graphical depictions of each section are presented in Appendix B. In addition, each surveyed section was plotted, overlain (where appropriate) and compared to the Pre-Construction year 1, 2, 3, and 4 graphs (Appendix C) and will be compared to subsequent annual cross-section graphs in order to assess changes to channel dimensions post-restoration.

Table 3-2. Results of cross-sectional survey analysis – Post-Restoration Year 4

Reach	Station	Feature	Bankfull Width (ft)	Mean Depth (ft)	Width/ Depth Ratio	Entrench-ment Ratio	Bankfull Area (ft^2)	Top of Bank Area (ft^2)
WC01*	2+24	Crossover/Riffle	24.5	0.9	27.0	1.7	22.1	148.4
	2+71	Meander/Pool	13.9	1.8	7.6	2.1	25.4	144.7
WC02*	0+74.5	Crossover/Riffle	11.9	0.6	18.6	1.2	7.6	35.3
	1+10	Pool	14.8	0.4	38.1	1.3	5.7	21.8
WC03	1+56	Crossover/Riffle	10.7	0.7	15.2	1.6	7.6	40.5
	2+08	Meander/Run	13.0	1.3	10.4	2.7	16.2	32.1
WC04	1+10	Meander/Pool	7.8	0.7	10.5	4.2	5.8	90.9
	1+68	Crossover/Riffle	9.4	0.3	27.4	1.4	3.3	55.7

*Cross-sections were re-established during Post-Restoration Year 1

3.1.2 Particle Size Analysis

The results of the pebble count data collected during the Post-Restoration Year 4 monitoring are shown in Table 3-3. Reachwide and riffle surface pebble counts indicate a D_{50} median particle size class ranging from coarse gravel to small cobble across all sites. Meander feature surface pebble counts indicate a D_{50} ranging from medium gravel to very coarse gravel, due to pool features yielding smaller particles which is especially evident at the control WC03 meander/pool cross-section. Riffle surface and reachwide D_{84} size classes range from small cobble to large cobble at all sites, with the largest particles found at sites WC01 and WC02. Similarly, meander feature surface pebble counts at all sites indicate a D_{84} median particle size class ranging from very coarse gravel to medium cobble. Complete particle size distribution charts are included in Appendix B.

Table 3-3. Particle size distribution – Post-Restoration Year 4

Riffle Feature Surface			***Meander Feature Surface***			***Reachwide***		
Measure	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
*WC01**								
D_{50}	42	very coarse gravel	D_{50}	25	coarse gravel	D_{50}	32	coarse gravel
D_{84}	110	medium cobble	D_{84}	84	small cobble	D_{84}	93	medium cobble
*WC02**								
D_{50}	82	small cobble	D_{50}	43	very coarse gravel	D_{50}	37	very coarse gravel
D_{84}	150	large cobble	D_{84}	100	medium cobble	D_{84}	80	small cobble
WC03								
D_{50}	36	very coarse gravel	D_{50}	12	medium gravel	D_{50}	31	coarse gravel
D_{84}	77	small cobble	D_{84}	44	very coarse gravel	D_{84}	71	small cobble
WC04								
D_{50}	49	very coarse gravel	D_{50}	20	coarse gravel	D_{50}	22	coarse gravel
D_{84}	92	medium cobble	D_{84}	58	very coarse gravel	D_{84}	75	small cobble

4.0 COMPARISONS BETWEEN YEARS

4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the four years of Pre-Restoration monitoring (2010-2015; Figure C-1). At the downstream-most part of the reach, the stream's thalweg followed along the left bank outside bend during the first year of survey with a large mid-channel bar separating the thalweg from a cutoff channel along the right bank. During the second and third years of monitoring (2012, 2013), the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows. During the fourth year of survey (2015) the thalweg continued to follow the channel along the right bank. Furthermore, a large tree along the left bank fell and was perpendicularly positioned in the stream through this section. The tree caused the stream to widen and flow over most of the mid-channel bar; however, during years 1 through 3 of Post-Restoration monitoring, the tree migrated onto the left bank, laying parallel, and the outside left bend channel now conveyed the majority of stream flow. During the year 4 Post-Restoration survey in 2020, channel conditions at this location were found to have aggraded substantially, and now the majority of stream flow occurs mid-channel throughout this portion of the profile. At the upstream-most part of the reach, the stream's pattern also changed. Stationing differed from above Cross-section 2 (Station 2+95) to the end of the reach. During the first year of monitoring (2010), the reach was 400 feet from top to bottom, but during all other years of Pre-Restoration monitoring the reach was 420 feet in length. Sinuosity above Cross-section 2 likely increased, adding length to the profile.

Changes in the cross-sections were also observed at WC01 between the four years of Pre-Restoration survey (Figures C-7, C-9). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+29) especially near the right bank between Pre-Restoration Years 1 and 2, while deposition was apparent near the left bank between Pre-Restoration Years 2 and 3. During Pre-Restoration Year 4, continued deposition was observed, and the cross-section once again closely resembled that of Pre-Restoration Year 1. Significant bank erosion and undercutting along the left bank (almost 6 feet) was observed at Cross-section 2 (Meander Bend at Station 2+95) during both the second and third years of monitoring (2012, 2013). Between Pre-Restoration Years 3 and 4, continued erosion occurred along the left bank increasing the depth of undercutting. Eroded sediment caused slight deposition along the left stream bed. This resulted in increases, from Pre-Restoration Year 1, of bankfull cross-sectional area and top of bank cross-sectional area at this station. Between Pre-Restoration Years 1 and 2, a side-bar formed on the right bank, burying the scour chain at this cross-section. The scour chain was not found during Pre-Restoration Years 3 and 4 of monitoring. In addition, the thalweg pattern changed between Pre-Restoration Years 1 and 2 so that it was no longer perpendicular to the permanently monumented cross-section markers at this location.

The first year of Post-Restoration monitoring was completed in 2017. The WC01 reach underwent an instream restoration and a new longitudinal profile and two cross-sections were selected and monitored for baseline conditions. Cross-section 1 was placed in a crossover riffle at Station 2+24, while Cross-section 2 was placed at a meander bend/pool at Station 2+71. The longitudinal profile extends 490 feet through the restored reach in Harford Glen. The survey of the longitudinal profile consisted of large riffle and pool features. During 2017, approximately 55.1% of the reach was riffle/run and 44.9% was pool/glide; in 2018, approximately 57.0% of the reach was riffle/run and 43.0% was pool/glide. During 2019, approximately 59.3% of the reach was riffle/run and 40.7% was pool/glide; in 2020, approximately 52.8% of the reach was riffle/run and 47.2% was pool/glide. The slope of the reach was high at 2.6% in 2017 and remained high at 2.7% from 2018 through 2020. The cross-sections featured stable banks exhibiting no erosion. Cross-section 1 at Station 2+24 has a defined bench and access to a small floodplain as the banks have been graded back during construction (Figure C-8). Cross-section 2 at Station 2+71 exhibits the same floodplain on the right bank in addition to a point bar, while the left bank is heavily armored by boulders (Figure C-10); between the Post-Restoration years 3 and 4 surveys, this armoring failed, resulting in several of the large boulders eroding out and falling into the stream channel, leaving the bank behind exposed to future erosion. Channel alterations were noted between the 2017 and 2018 Post-Restoration surveys. Minimal scouring (approximately 0.25 feet) of the channel at Cross-section 1 was observed, while significant aggradation of sediment was found along the right bank and channel at Cross-section 2. These changes in streambed were likely the result of an abnormally wet spring, and year overall, which shifted and transported large amounts of sediment throughout the reach. Between the 2018 and 2019 Post-Restoration surveys, channel alteration was again noted. Aggradation of approximately 1.0 feet occurred in the middle of the channel at Cross-section 1, and approximately 1.0 feet of sediment was deposited on the right bank bench was observed; significant aggradation of sediment was found along the right bank and channel at Cross-section 2. Channel alteration was again noted between the 2019 and 2020 Post-Restoration surveys. The channel was noted to have scoured between 0.5 and 0.75 feet across the majority of the channel at Cross-section 1, and approximately 0.5 feet of scouring of the bench on the right bank was observed; significant scouring of approximately 1.0 feet was found along the left and right banks, with mid-channel conditions remaining the same, at Cross-section 2. The changes in streambed were significant between 2020 and prior year surveys, likely the result of an extensive rains which shifted and transported large amounts of sediment throughout the reach. Future surveys will be useful in determining how the stream channel reacts to these changes, as well as how it stabilizes over time.

At WC01, D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections, and reachwide (Table C-3). D_{84} particle size classes changed between Years 1 and 2, coarsening at Cross-section 1 (Crossover Riffle at Station 2+29) from medium to large cobble, and becoming slightly finer at Cross-section 2 (Meander Bend at Station 2+95) from medium to small cobble. Although D_{84} classes at Cross-section 2 were unchanged between Years 2 and 3 they transformed during the fourth year of study, increasing from small cobble to medium cobble. Reachwide D_{84} particle size class fluctuated between large cobble during Year 1, to medium cobble during Year 2 and back to large cobble during Years 3 and 4.

In the first year of Post-Restoration (2017), D_{50} particle sizes decreased from very coarse gravel to medium gravel at the meander feature and from very coarse gravel to coarse gravel reachwide. In Post-Restoration Years 2 and 3, reachwide D_{50} particle sizes increased back to very coarse gravel reachwide but fluctuated between medium and very coarse gravel at the meander feature. D_{50} particle sizes categorized as coarse gravel at both the meander feature and reachwide in Post-Restoration Year 4. Riffle feature surface D_{50} particle sizes remained as very coarse gravel during all 4 years of post-restoration monitoring. In the first year of Post-Restoration monitoring (2017), reachwide D_{84} decreased to small cobble. The new crossover riffle at Station 2+24 had a D_{84} of small cobble and the new meander bend/pool at Station 2+71 had a D_{84} of very coarse gravel. In 2018, the reachwide D_{84} increased to large cobble. The crossover riffle at Station 2+24 had an increased D_{84} to large cobble and the meander bend/pool at Station 2+71 had an increased D_{84} to medium cobble. In 2019, the reachwide D_{84} decreased to small cobble. The crossover riffle at Station 2+24 had a decreased D_{84} to very coarse sand and the meander bend/pool at Station 2+71 had a decreased D_{84} to medium gravel. This overall decrease in particle size classes at WC01 was likely the result of an increase in smaller particles being transported and deposited into the reach from the above average rainfall received between 2018 and 2019. In 2020, the reachwide D_{84} increased to medium cobble. The crossover riffle at Station 2+24 had an increased D_{84} to medium cobble and the meander bend/pool at Station 2+71 had an increased D_{84} to small cobble. This overall increase in particle size classes at WC01 was likely the result of an increase in larger particles being transported and deposited into and within the reach from the above average rainfall intensities between 2019 and 2020, with enough power to redistribute larger substrate, as evidenced by the movement of the large armoring boulders at Station 2+71.

4.2 WC02

Significant changes in profile were not observed at WC02 over the four years of Pre-Restoration study. The most noticeable change is a pool feature once approximately at Station 1+00 changed to Station 0+80 (Figures C-3 and C-4). Reach length remained constant and stream slope measurements were fairly consistent overall. Feature proportions within the reach have fluctuated from year to year. While the percentage of glides increased from 0% to 16.7% between Pre-Restoration Years 1 and 2, the percentage of pools declined each year. During the fourth year (2015), 25.5% of the surveyed reach was classified as pools and glides, the lowest percentage since monitoring began. In contrast, riffles and runs made up 74.5% of the surveyed reach which was the greatest percentage of all four years (Table C-1).

Following Pre-Restoration Year 1, bed aggradation occurred at Cross-section 1 (Crossover Riffle at Station 1+38), but banks here remained relatively stable (Figure C-11). There was little change between the third and fourth year of Pre-Restoration study. Conversely, channel scour occurred at Cross-section 2 (Meander Bend at Station 3+24), as well as slight erosion of the upper portion of the right bank (Figure C-13). At this station, a bankfull bar exists along the left bank which showed little change between Pre-Restoration Years 2 and 3 of the study. However, during the fourth year of Pre-Restoration monitoring slight degradation can be seen along the left bank and bar.

In the first year of Post-Restoration monitoring, the WC02 reach consisted of 63.6% riffle/run and 36.4% pool/glide (Table C-1). This reach consisted of 60.3% riffle/run and 39.7% pool/glide in the 2018 Post-Restoration monitoring. During 2019 Post-Restoration monitoring, this reach consisted of 61.5% riffle/run and 38.5% pool/glide; the percent riffle/run and percent pool/glide was 59.0% and 41.0% during the 2020 Post-Restoration monitoring, respectively. This reach underwent instream restoration that has straightened the channel causing the meander bend cross-section to be placed in a straight pool. Overall, this reach is still somewhat lacking access to an immediate floodplain, but the banks are stable and well-vegetated despite being steep and high. The entrenchment ratio was low, 1.3, in 2017, and remained low at 1.4 in 2018 and 2019, and 1.3 in 2020, indicating the stream is confined within the banks (Appendix B). The stream is comprised predominately of long riffles and grade control steps into long/wide pools. Cross-section 1 was newly monumented in a pool at Station 0+74.5 (Figure C-12) and Cross-section 2 was monumented at Station 1+10 in a crossover riffle (Figure C-14). Both cross-sections exhibit little bank erosion and have stable banks. Cross-section 1 aggraded substantially in 2018, with more than 1.5 feet of substrate deposited in the stream channel. Significant aggradation continued in 2019, with an additional 0.5 feet of sediment deposited in the stream channel; conditions at Cross-section 1 were comparable between the 2019 and 2020 surveys. Cross-section 2 had minimal scouring (0.25 to 0.5 feet) within the channel in 2018, but experienced aggradation of 0.25 to 1.0 feet of substrate in 2019. Aggradation at this station continued in 2020, with an additional 0.25 feet of sediment being deposited. These changes in streambed could be the result of an abnormally wet years overall between 2018 and 2020, which likely shifted and transported large amounts of sediment throughout the reach. Future surveys will enable evaluation of how the stream channel reacts to these changes, as well as how it stabilizes over time.

D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections. The reachwide D_{50} for Pre-Restoration Years 2 and 3 were categorized as coarse gravel which is slightly finer than the very coarse gravel observed in Pre-Restoration Years 1 and 4 (Table C-3). D_{84} particle size classes became slightly finer at both cross-sections, diminishing from medium-sized cobble to small cobble between the first and second years of Pre-Restoration study. Furthermore, both cross-section D_{84} classes coarsened between Pre-Restoration Years 3 and 4 from small cobble to medium cobble. Although reachwide D_{84} particle sizes also reduced between Pre-Restoration Years 1 and 2, particles increased back to medium-sized cobble in Pre-Restoration Year 3 and remained during Pre-Restoration Year 4.

In the first year of Post-Restoration study (2017), D_{50} particle size classes decreased at both cross-sections and reachwide, classifying as coarse gravel at the riffle feature, very fine gravel at the meander feature, and medium gravel reachwide. Riffle feature D_{50} classification rebounded back into the very coarse gravel category in the Post-Restoration Years 2 and 3 surveys, and meander feature D_{50} particle sizes coarsened to small cobble in 2018 and medium gravel in 2019. In the Post-Restoration Year 4 survey, riffle feature D_{50} coarsened to small cobble and meander feature D_{50} coarsened to very coarse gravel. Reachwide D_{50} classifications rated as very coarse gravel in the Post-Restoration Year 4 assessment, and coarse gravel in both Post-Restoration Years 2 and 3 surveys, all coarser than the initial particle class determined by the Post-Restoration Year 1 survey, and recategorized for the first time the same as pre-restoration ratings. Reachwide D_{84} decreased to medium gravel in 2017. The new crossover riffle at Station 1+10 had a D_{84} of very coarse gravel and the new meander bend/pool at Station 0+74.5 had a D_{84} of medium gravel. In the 2018 Post-Restoration study, the reachwide D_{84} increased to coarse gravel. The crossover riffle at Station 1+10 had an increased D_{84} to medium cobble and the meander bend/pool at Station 0+74.5 had an increased D_{84} to large cobble. In the 2019 Post-Restoration study, the reachwide D_{84} increased to small cobble. The D_{84} at the crossover riffle at Station 1+10 remained as medium cobble and the meander bend/pool at Station 0+74.5 had a decreased D_{84} to small cobble. In the 2020 Post-Restoration Year 4 study, the reachwide D_{84} remained as small cobble. The D_{84} at the crossover riffle at Station 1+10 coarsened to large cobble and the meander bend/pool at Station 0+74.5 had an increased D_{84} to medium cobble.

4.3 WC03

Pool and glide features have previously dominated reach WC03, as 65.6% and 67.5% of the reach was made up of pools and glides during Pre-Restoration Years 1 and 2, respectively. During Pre-Restoration Year 3, however, riffles and runs made up more than half (53.1%) of the reach (Table C-1). Pools and glides were dominant during Pre-Restoration Year 4 (58.5%). Changes in longitudinal profile were noted between the four years' of Pre-Restoration study, most notably the deepening of most pools reachwide between the first two years (Figure C-5). Pool depth has stayed consistent from Pre-Restoration Year 2 through Year 4 except for the pool feature at station 1+00 which has deepened about a foot.

In Post-Restoration Year 1 (2017), WC03 consisted of 66.0% riffle/run and 34% pool/glide which shows a large change from Pre-Restoration Year 4 (2015) when pools and glides were dominant. These percentages were similar in subsequent surveys, with the reach consisting of 62.7% riffle/run and 37.2% pool/glide in 2018 and 62.3% riffle/run and 37.7% pool/glide in 2019. In the Post-Restoration Year 4 survey, riffle/run to pool/glide distributions transitioned closer to Pre-Restoration distributions, consisting of 50.0% riffle/run and 50.0% pool/glide. No instream restoration occurred on this reach and the stream had aggraded over time prior to 2018 (Figure C-5). Many of the pools became shallower due to this aggradation and some transitioned into riffles or runs altogether. Slight scouring was noted in this reach during the 2018 survey when compared to prior monitoring, mostly constrained to the upper 100 feet of the profile. This scouring continued in 2019 and 2020 and was evident throughout the reach instead of constrained to the upper 100 feet of the profile, likely due to above average rainfall between 2018 and 2020 which transported substrate out of the reach.

Cross-section 1 (Station 1+55) had been a crossover riffle when initially established during Pre-Restoration Year 1 of the study and again in Pre-Restoration Years 3 and 4. However, changes in channel profile resulted in the riffle feature migrating downstream, and this cross-section was within a pool feature when surveyed in Pre-Restoration Year 2 (Figure C-5). As a result, Year 2 bankfull cross-sectional dimensions changed significantly at this station, with the deepening of the channel bed (Table C-2). The Pre-Restoration Year 4 streambed most closely resembled that of the Pre-Restoration Year 2 study. The right streambank remained relatively unchanged at Cross-section 1 throughout the four-year Pre-Restoration study while the left bank slightly filled in between 2012 and 2015 (Figure C-15). Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+07), and erosion of the outside (left) bank was also observed between Pre-Restoration Years 1 and 2 (Figure C-16). The left bank continued to erode between Pre-Restoration Years 2 and 3 while aggradation occurred in the stream bed near the left bank. Significant erosion continued on the left bank between Pre-Restoration Years 3 and 4 as well as scouring of the left bank streambed. Consequently, bankfull cross-sectional dimensions and entrenchment ratios also differed significantly at this station between all four Pre-Restoration years (Table C-2).

In the first year of Post-Restoration monitoring, Cross-section 1 at Station 1+56 continued eroding slightly on the left bank while the right bank aggraded around the toe of the bank almost 0.5 feet (Figure C-15). In 2018, the left bank stabilized, while scouring occurred around the toe of both the left and right banks. Erosion of the left bank was evident again during the 2019 survey while the toe of the left bank aggraded; measurements across the right bank demonstrated that it has remained stable. Erosion of the left bank was evident during the 2019 and 2020 surveys while the toe of the left bank aggraded in 2019 and remained similar in 2020; measurements across the right bank demonstrated that it has remained stable during Post-Restoration Years 1 through 3 surveys, but aggraded approximately 0.33 feet in the Post-Restoration Year 4 survey. Cross-section 2 at Station 2+08 has undergone major changes since Pre-Restoration Year 4 (2015). The left bank has eroded an additional 4.0 to 6.5 feet from 2015 to 2020 and has undercut the bank; the left bank at Cross-section 2 eroded away enough between 2018 and 2019 to cause the left end pin of the cross-section to fall into the stream channel, making it necessary for the field crew to install a new end pin further up the bank (Figure C-16). The streambed at this cross-section continues to scour significantly on the left side of the channel and aggrade on the right side of the channel due to the encroaching point bar.

At Cross-section 1 (crossover riffle at Station 1+55), channel substrate became finer, with the D_{50} decreasing from very coarse gravel to coarse gravel between Pre-Restoration Years 1 and 3 (Table C-3). During Pre-Restoration Year 4, D_{50} increased and was once again categorized in the very coarse gravel size class. The D_{84} decreased from small cobble to very coarse gravel and back to small cobble over the four years of Pre-Restoration monitoring. In Post-Restoration Year 1, the D_{50} decreased to coarse gravel and the D_{84} remained very coarse gravel; the Post-Restoration Year 2 D_{50} remained coarse gravel and the D_{84} increased to small cobble. In Post-Restoration Year 3, the D_{50} increased to very coarse gravel and the D_{84} increased to small cobble; the Post-Restoration Year 4 D_{50} remained very coarse gravel and the D_{84} remained small cobble.

The D_{84} decreased at Cross-section 2 (Meander Bend at Station 2+07) from small cobble in Pre-Restoration Year 1 to very coarse gravel in Pre-Restoration Years 2 and 3 to coarse gravel in Pre-Restoration Year 4. At Cross-section 2, D_{50} particle size classes remained the same between the first two years of Pre-Restoration study (medium gravel) and increased during the third (coarse gravel). During the fourth Pre-Restoration year, D_{50} size decreased from coarse gravel to fine gravel. In Post-Restoration Years 1 and 2, the D_{50} increased to medium gravel and the D_{84} increased to very coarse gravel. In Post-Restoration Year 3, the D_{50} decreased to coarse gravel and the D_{84} remained small cobble; the Post-Restoration Year 4 D_{50} decreased to medium gravel and the D_{84} decreased to very coarse gravel.

Reachwide, the D_{50} was coarse gravel during three of the four Pre-Restoration study years with a slight increase to very coarse gravel occurring in Year 3. The D_{84} showed the same pattern as the D_{50}, increasing only during Pre-Restoration Year 3 to large cobble and remaining in the same small cobble class Pre-Restoration Years 1, 2, and 4. During the first Post-Restoration year (2017), the reachwide D_{50} was medium gravel and D_{84} was very coarse gravel; the reachwide D_{50} increased to coarse gravel in 2018, and D_{84} remained very coarse gravel, continuing the trend to smaller material than in years past. The reachwide D_{50} remained as coarse gravel in 2019, and D_{84} increased to small cobble, discontinuing the trend to smaller materials from years past. The reachwide D_{50} remained as coarse gravel and D_{84} remained small cobble in 2020. Future monitoring is needed to determine if the particle size distribution is stabilizing in this reach, or if continued erosion will result in shifting particle size distributions throughout this reach.

4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the four years of Pre-Restoration study. However, during Pre-Restoration Years 2 through 4 surveys and the Post-Restoration Year 1 survey, the stream channel was dry from above the pool feature at Station 1+80 to the top of the reach at Station 3+00 and beyond; the streambed was found to be mostly dry from Station 2+50 to the top of the reach in the Post-Restoration Year 2 survey. Around this same station and above, channel aggradation can be seen when comparing the profiles of the initial year and all the following years' surveys (Figure C-6) which may explain the decrease in water depth between these surveys. While no significant channel alterations were noted during the Post-Restoration Years 3 and 4 surveys, this reach was found to have water throughout the entire longitudinal profile both years; further studies are needed to determine if the increased extent of water will remain permanent at WC04 or if it was the result of above normal rainfall between 2018 and 2020 and will dry up in future years. Reach length, slope, and proportion of features within the reach remained relatively unchanged (Table C-1).

Similar to the profile, the cross-sections within this reach also remained relatively unchanged between the first three years of Pre-Restoration study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) between Pre-Restoration Years 1 through 3 (Figure C-17). During Pre-Restoration Year 4, erosion on the lower left bank continued and was more apparent resulting in higher bankfull and width depth dimensions. This station was identified as a riffle located just above the top of a pool during the initial year of Pre-Restoration monitoring, but was within part of the pool when surveyed in all other subsequent Pre-Restoration years. The channel was actively widening and cutting into the bank at this station during the Pre-Restoration Year 4 survey, resulting in changes in cross-sectional dimensions. This undercutting continued to take place in Post-Restoration Years 1 through 4 (Table C-2). The overall top of bank area slightly decreased again in 2019 and remained very similar in 2020, due to the growing point bar and bench, while bankfull area slightly increased from the 2018 survey (Figure C-17). Cross-section 1 at Station 1+10 is now in a meander pool feature in Post-Restoration Years 1 through 4, a change from the original riffle feature in Pre-Restoration Year 1 and the pool feature in Pre-Restoration Years 2 through 4 (Table C-2). Cross-section 2 at Station 1+68 remains unchanged and stable through Post-Restoration Year 4, with slight aggradation occurring on the right side of the channel in Post-Restoration Years 1 and 2 (Figure C-18).

Reachwide D_{84} particle size classes remained the same during all four Pre-Restoration years (small cobble), decreased in Post-Restoration Years 1 and 2 to very coarse gravel, and increased back to small cobble in Post-Restoration Year 3 (Table C-3). D_{84} remained the same at Cross-section 1 during the first three years of Pre-Restoration study (small cobble) and decreased during the fourth year to coarse gravel, where it remained in Post-Restoration Year 1. An increase in D_{84} to very coarse gravel was noted at Cross-section 1 in 2018, and again to small cobble in 2019. D_{84} at Cross-section 1 in 2020 coarsened for a fourth straight year to medium cobble. At Cross-section 2, D_{84} decreased from small cobble to very coarse gravel between Pre-Restoration Years 2 and 3. It increased back to small cobble between Pre-Restoration Years 3 and 4 and had remained small cobble through Post-Restoration Year 2. D_{84} decreased from small cobble to coarse gravel between Post-Restoration Years 2 and 3 and increased from coarse gravel to very coarse gravel between Post-Restoration Years 3 and 4 (Table C-3).

Reachwide D_{50} particle size class increased from coarse gravel to very coarse gravel between Pre-Restoration Years 2 and 3 and decreased back to coarse gravel during Pre-Restoration Year 4 for the reachwide survey. During the Post-Restoration Year 1 survey, the reachwide D_{50} slightly decreased to medium gravel, but increased back to coarse gravel in the 2018 through 2020 studies (Table C-3). Cross-section 1 D_{50} has fluctuated by decreasing from medium gravel to very coarse sand and again increasing to medium gravel and Cross-section 2 remained the same (very coarse gravel) between Pre-Restoration Years 2, 3, and 4. In Post-Restoration Year 1, the D_{50} at Cross-section 1 remained medium gravel while the D_{50} at Cross-section 2 decreased to coarse gravel. Post-Restoration Year 2 results showed that the D_{50} at Cross-section 1 decreased again to very coarse sand while the D_{50} at Cross-section 2 increased back to very coarse gravel. Post-Restoration Year 3 results showed that the D_{50} at Cross-section 1 remained as very coarse sand while the D_{50} at Cross-section 2 decreased to coarse gravel. The Post-Restoration Year 4 assessment found the D_{50} at Cross-section 1 coarsened to very coarse gravel, while the D_{50} at Cross-section 2 remained coarse gravel (Table C-3).

5.0 CONCLUSIONS

The data presented herein provide an assessment of geomorphic conditions within the Wheel Creek watershed prior to and following completion of restoration efforts. During the Pre-Restoration Years 1 and 2 studies, none of the planned restoration projects had been completed within this watershed. During the Pre-Restoration Year 3 study, two planned restoration projects had been constructed while the remaining projects were still in planning stages. Continued planning occurred during Pre-Restoration Year 4 but no new construction activities were initiated. Restoration activities were all completed as of the Post-Restoration Year 1 survey; thus the 2020 survey is the fourth annual assessment following completion of restoration. Results of the geomorphic monitoring show that bank erosion continues to be prevalent in the two reaches (WC03, WC04) that did not receive stream restoration, but has improved in those reaches where instream channel restoration activities took place (WC01, WC02). Erosion of stream banks not only increases the sediment supply to the watershed but also provides a potential source of nutrients, especially phosphorus. Stream bank erosion is a common symptom of streams like those in Wheel Creek, where urban land cover is dominant (46.1%), contributing large amounts of impervious cover (21.4%) to the watershed (Becker, 2011). Efforts have been made to decrease the impact of damaging storm water flow causing erosion among the unstable banks. The two reaches that were restored (WC01, WC02) have stable, vegetated banks in each Post-Restoration survey and improved floodplain access in some areas but are still somewhat entrenched in others. In both restored reaches, surveyed cross-sections exhibited aggradation in the four years following completion of restoration; the undermining and failure of the bank armoring at station WC01 Cross-section 2 found in 2020 could compromise the stability of the bank and effectiveness of the restoration if not replaced. These streams may continue to adjust in the coming years, especially during high flow events. Future Post-Restoration monitoring will enable assessment of their stability and the effects of the restoration activities that occurred.

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6.0 REFERENCES

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APPENDIX A

PHOTOS

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WC01 – Facing downstream at Station 4+50

WC01 - Facing downstream at Station 3+00

WC01 – Facing downstream at Station 2+00

WC01 – Facing downstream at Station 1+00

Geomorphic Assessment Photos – Longitudinal Profiles

WC01 – Facing upstream from Station 0+00

WC02 – Facing upstream at Station 3+00

WC02 – Facing upstream at Station 2+00

WC02 – Facing upstream at Station 1+00

WC02 – Facing upstream at Station 0+50

WC02 – Facing upstream at Station 0+00

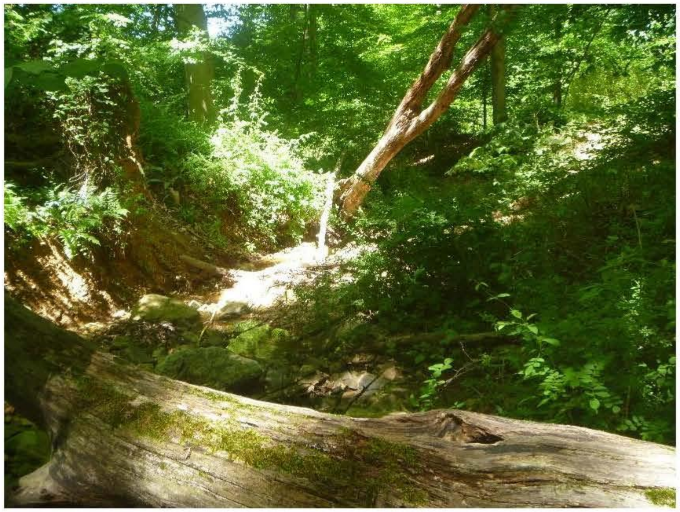
WC03 – Facing downstream at Station 3+08

WC03 – Facing downstream at Station 2+50

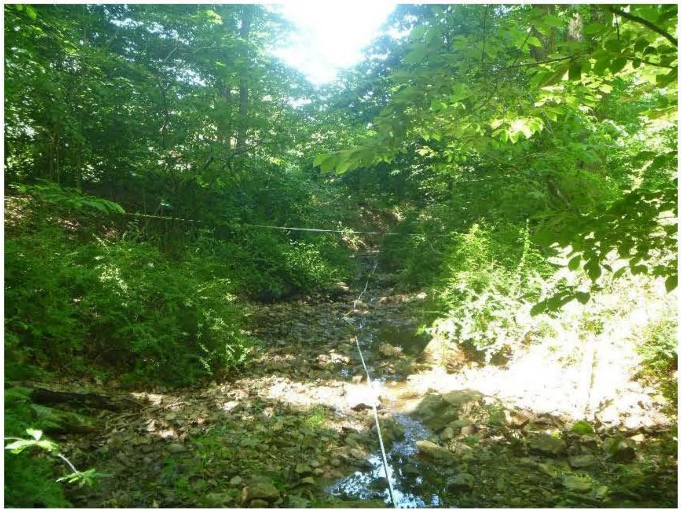
WC03 – Facing downstream at Station 1+50

WC03 – Facing downstream at Station 0+50

WC03 – Facing upstream at Station 0+00



WC04 – Facing downstream at Station 3+00


WC04 – Facing downstream at Station 2+00


WC04 – Facing downstream at Station 1+00


WC04 – Facing downstream at Station 0+50


WC04 – Facing upstream at Station 0+00

WC01 – XS-1 facing upstream

WC01 – XS-1 facing downstream

WC01 – XS-1 facing right bank

WC01 – XS-1 facing left bank

WC01 – XS-2 facing upstream

WC01 – XS-2 facing downstream

WC01 – XS-2 facing right bank

WC01 – XS-2 facing left bank

WC02 – XS-1 facing upstream

WC02 – XS-1 facing downstream

WC02 – XS-1 facing right bank

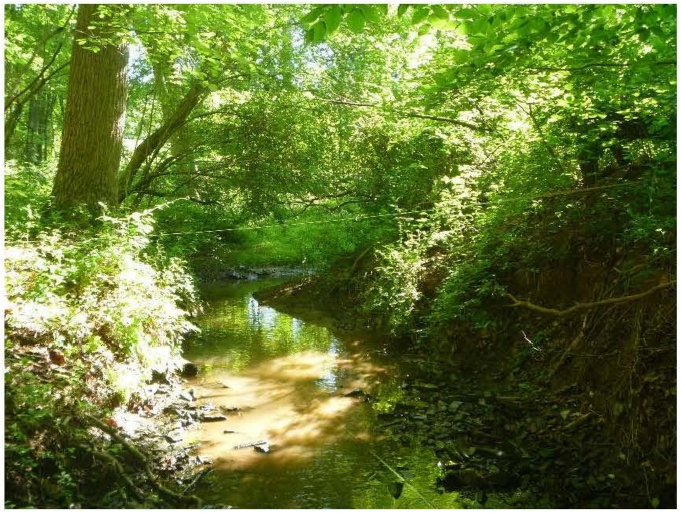
WC02 – XS-1 facing left bank

WC02 – XS-2 facing upstream

WC02 – XS-2 facing downstream

WC02 – XS-2 facing right bank

WC02 – XS-2 facing left bank



WC03 – XS-1 facing upstream

WC03 – XS-1 facing downstream

WC03 – XS-1 facing right bank

WC03 – XS-1 facing left bank

WC03 – XS-2 facing upstream

WC03 – XS-2 facing downstream

WC03 – XS-2 facing right bank

WC03 – XS-2 facing left bank

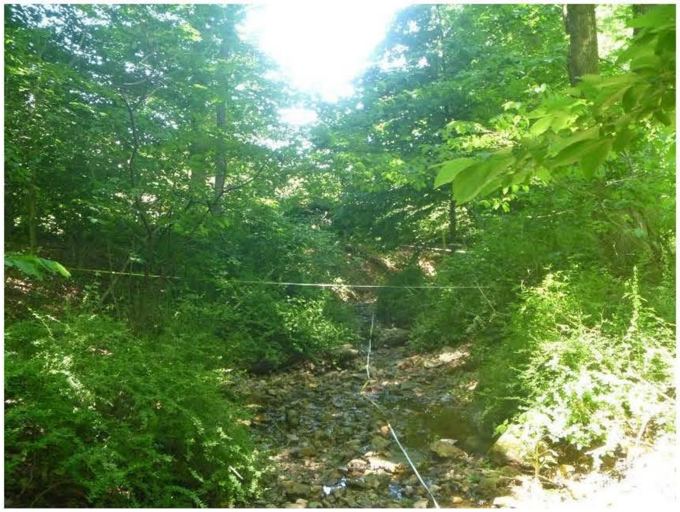

WC04 – XS-1 facing upstream


WC04 – XS-1 facing downstream


WC04 – XS-1 facing right bank


WC04 – XS-1 facing left bank


WC04 – XS-2 facing upstream


WC04 – XS-2 facing downstream


WC04– XS-2 facing right bank


WC04 – XS-2 facing left bank

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APPENDIX B

GEOMORPHIC ASSESSMENT DATA

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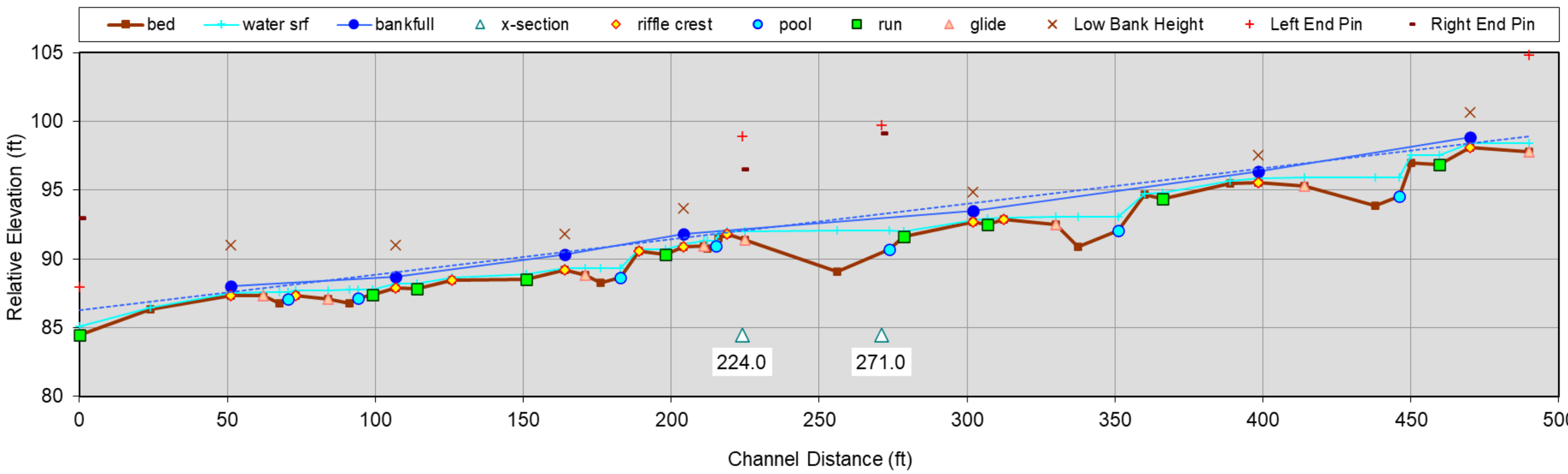
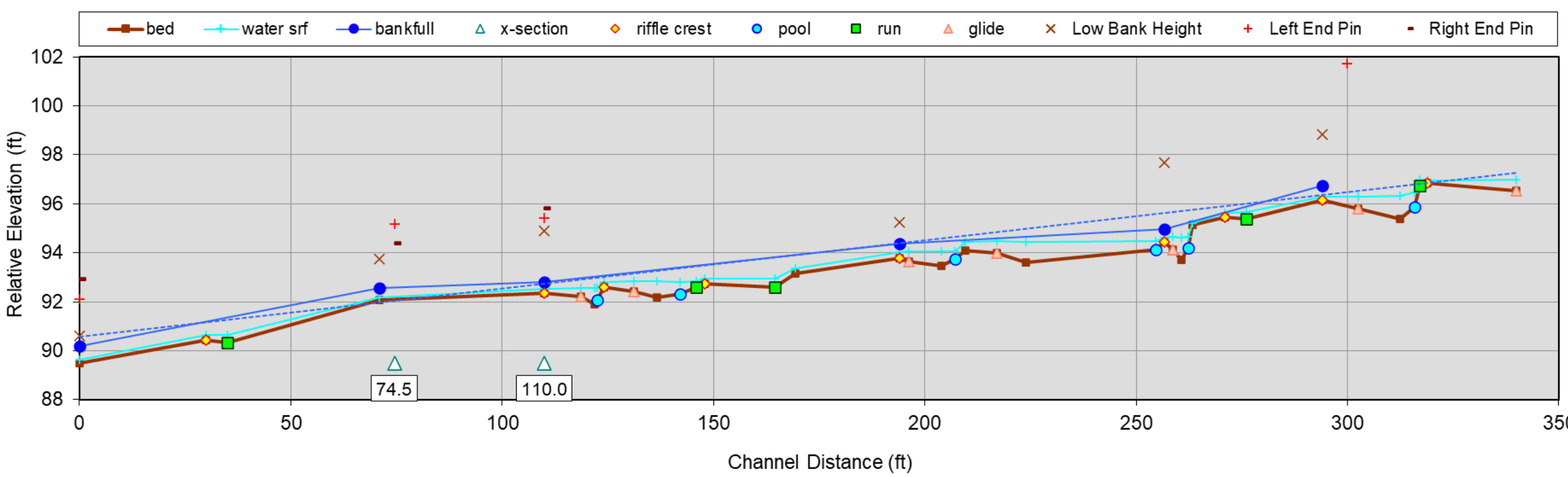
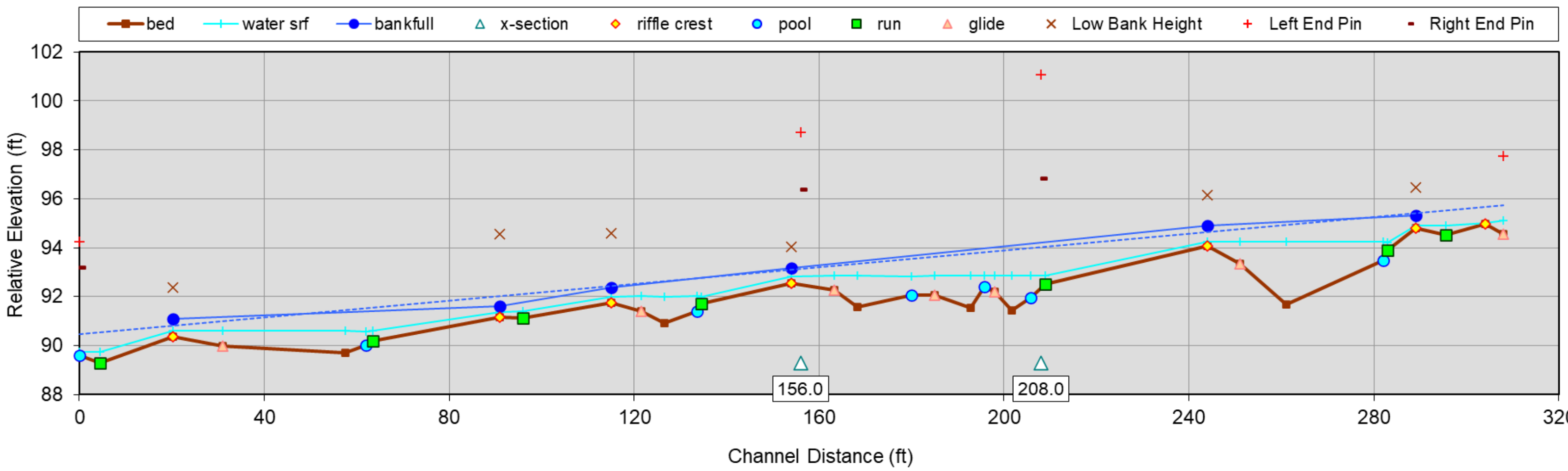
Wheel Creek WC01 2020



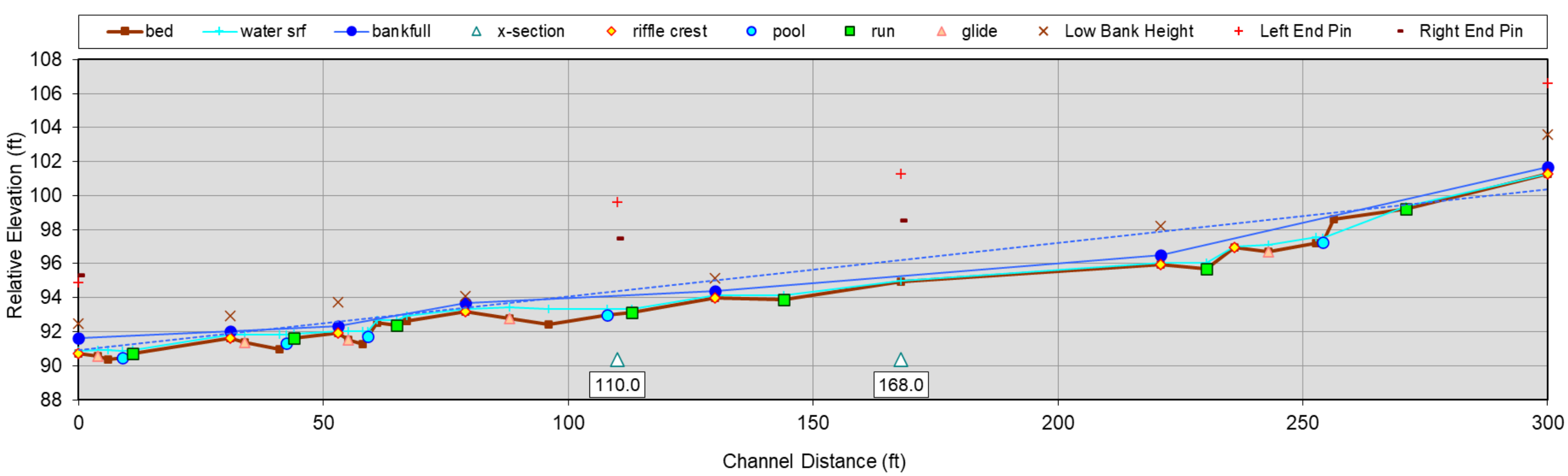
Wheel Creek WC02 2020

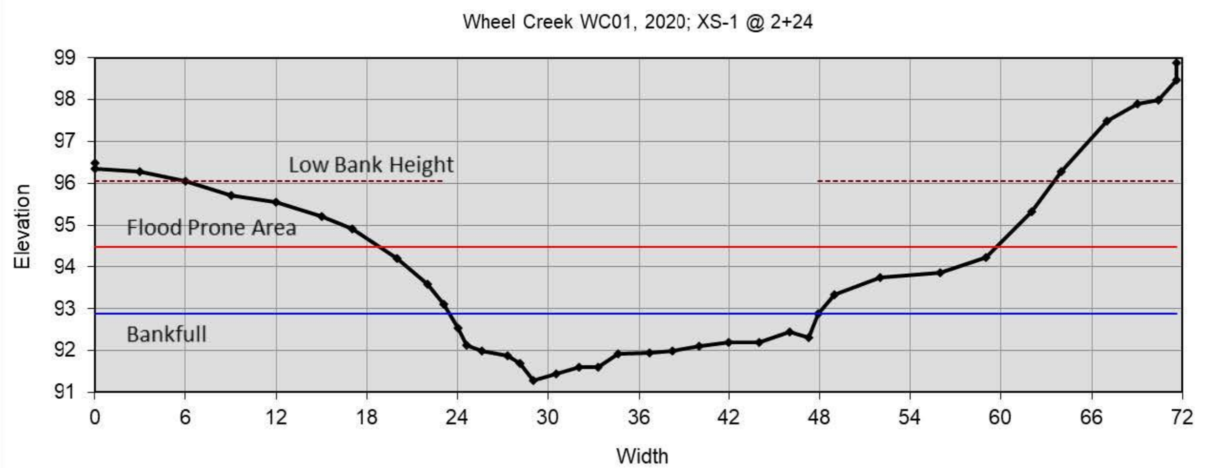


Wheel Creek WC03 2020

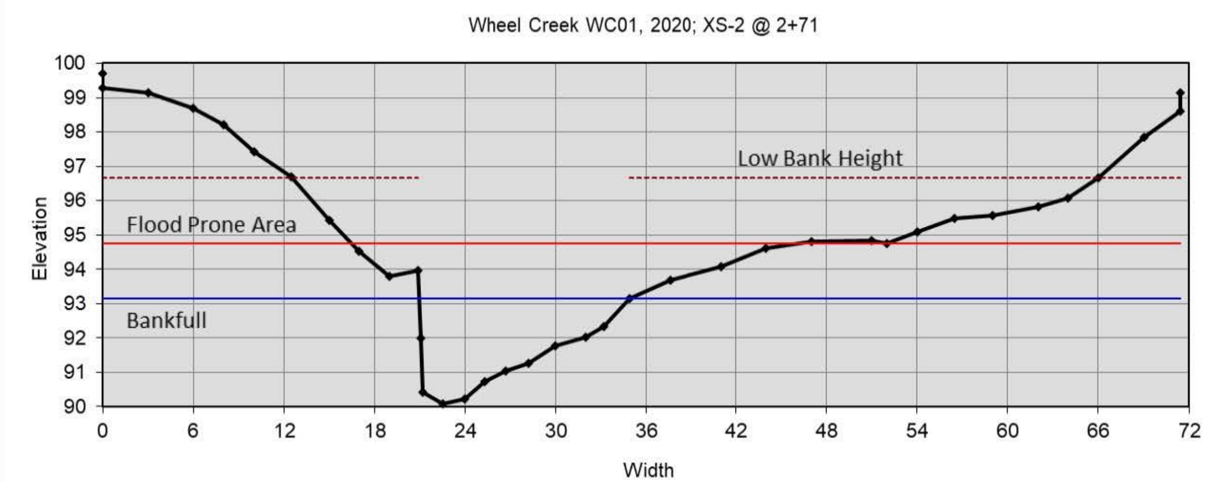


Wheel Creek WC04 2020

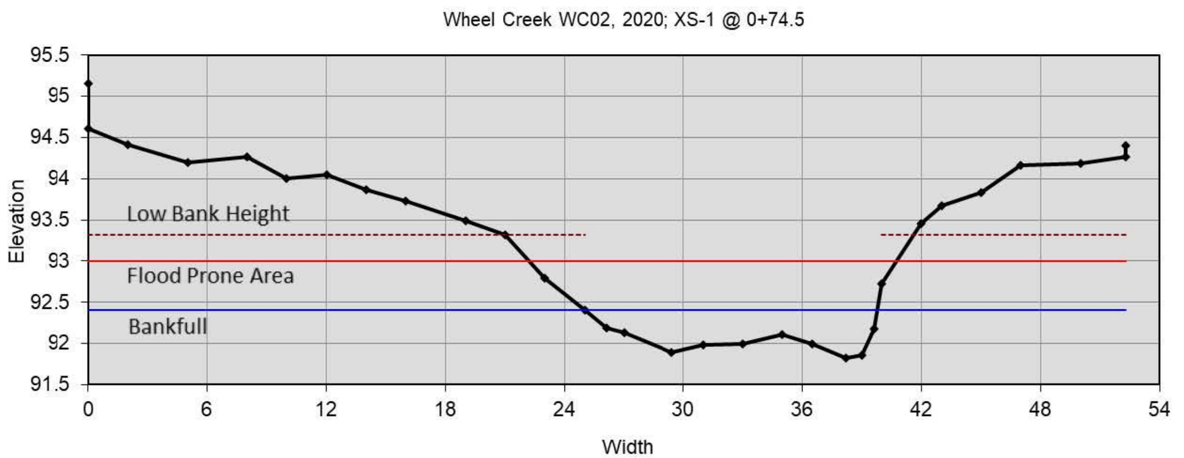




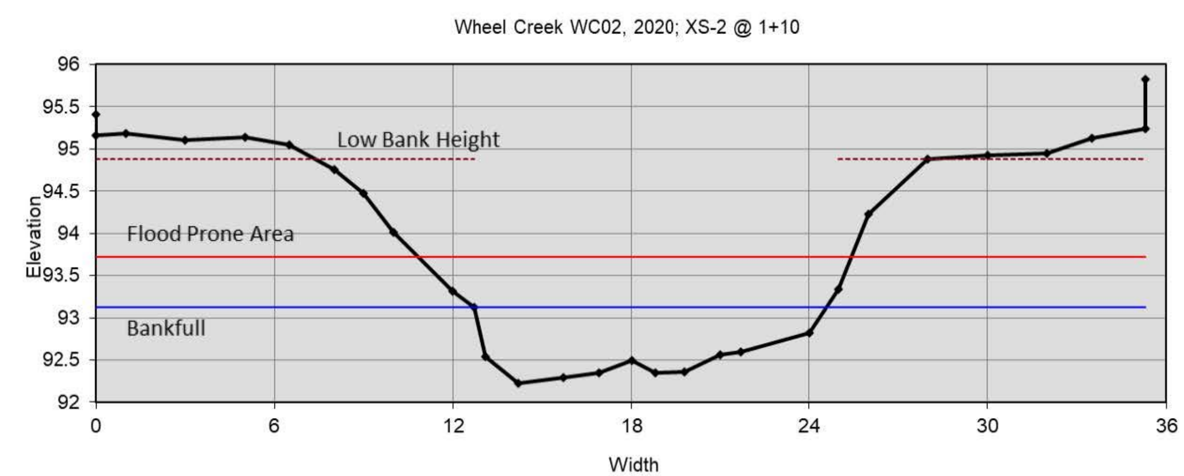
Bankfull Dimensions		Flood Dimensions		Materials	
22.1	x-section area (ft.sq.)	40.9	W flood prone area (ft)	42	D50 Riffle (mm)
24.5	width (ft)	1.7	entrenchment ratio	110	D84 Riffle (mm)
0.9	mean depth (ft)	4.8	low bank height (ft)	51	threshold grain size (mm):
1.6	max depth (ft)	3.0	low bank height ratio		
25.1	wetted parimeter (ft)				
0.9	hyd radi (ft)				
27.0	width-depth ratio				



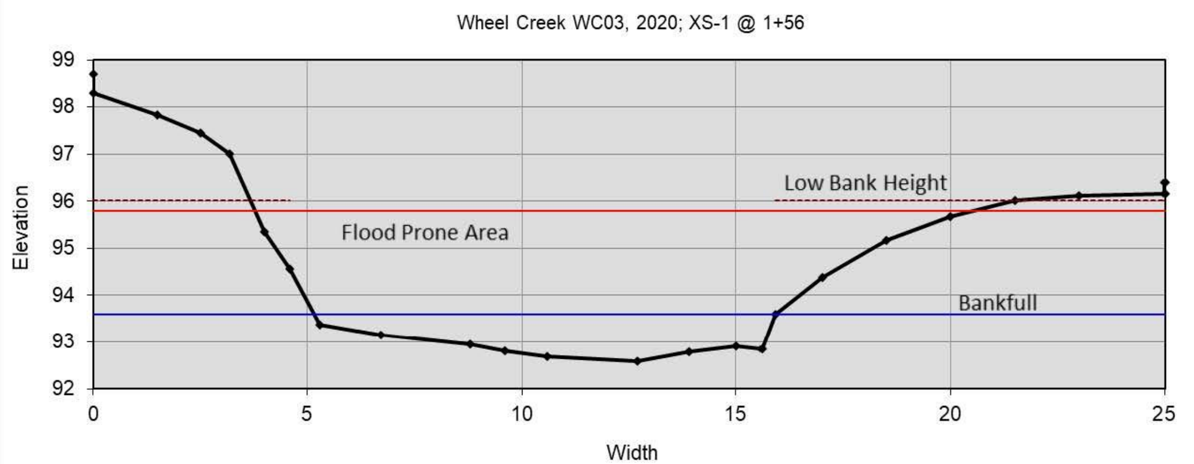
Bankfull Dimensions		Flood Dimensions		Materials	
25.4	x-section area (ft.sq.)	29.4	W flood prone area (ft)	42	D50 Riffle (mm)
13.9	width (ft)	2.1	entrenchment ratio	110	D84 Riffle (mm)
1.8	mean depth (ft)	6.6	low bank height (ft)	51	threshold grain size (mm):
3.1	max depth (ft)	2.1	low bank height ratio		
16.9	wetted parimeter (ft)				
1.5	hyd radi (ft)				
7.6	width-depth ratio				



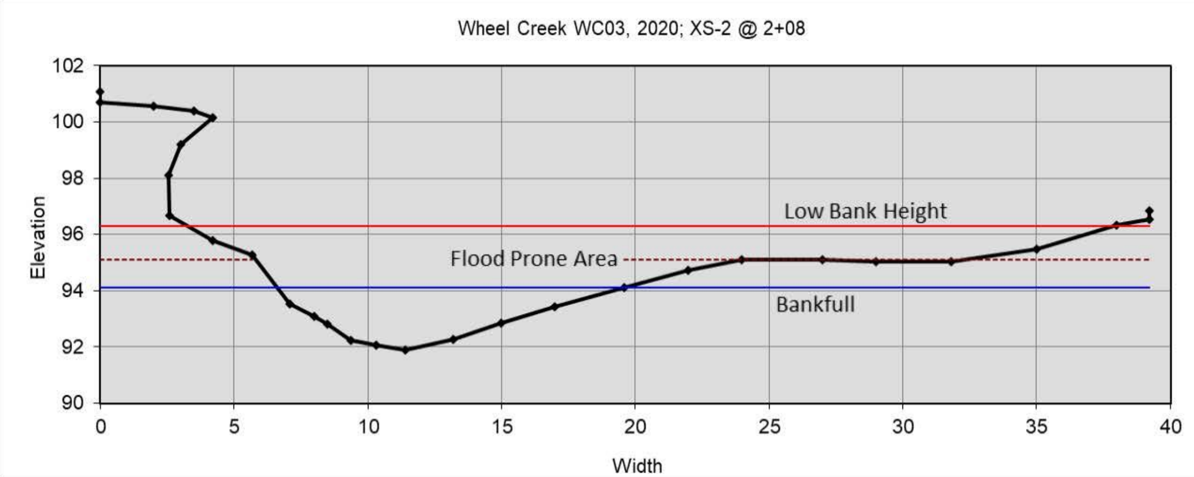
Bankfull Dimensions		Flood Dimensions		Materials	
5.7	x-section area (ft.sq.)	18.5	W flood prone area (ft)	82	D50 Riffle (mm)
14.8	width (ft)	1.3	entrenchment ratio	150	D84 Riffle (mm)
0.4	mean depth (ft)	1.5	low bank height (ft)	28	threshold grain size (mm):
0.6	max depth (ft)	2.5	low bank height ratio		
15.0	wetted parimeter (ft)				
0.4	hyd radi (ft)				
38.1	width-depth ratio				



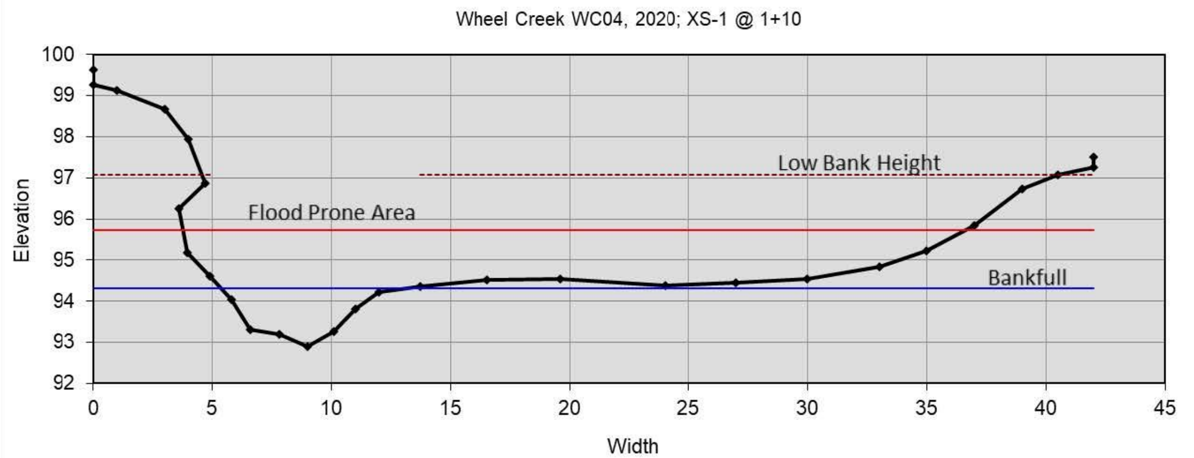
Bankfull Dimensions		Flood Dimensions		Materials	
7.6	x-section area (ft.sq.)	14.6	W flood prone area (ft)	82	D50 Riffle (mm)
11.9	width (ft)	1.2	entrenchment ratio	150	D84 Riffle (mm)
0.6	mean depth (ft)	2.7	low bank height (ft)	36	threshold grain size (mm):
0.9	max depth (ft)	2.9	low bank height ratio		
12.4	wetted parimeter (ft)				
0.6	hyd radi (ft)				
18.6	width-depth ratio				



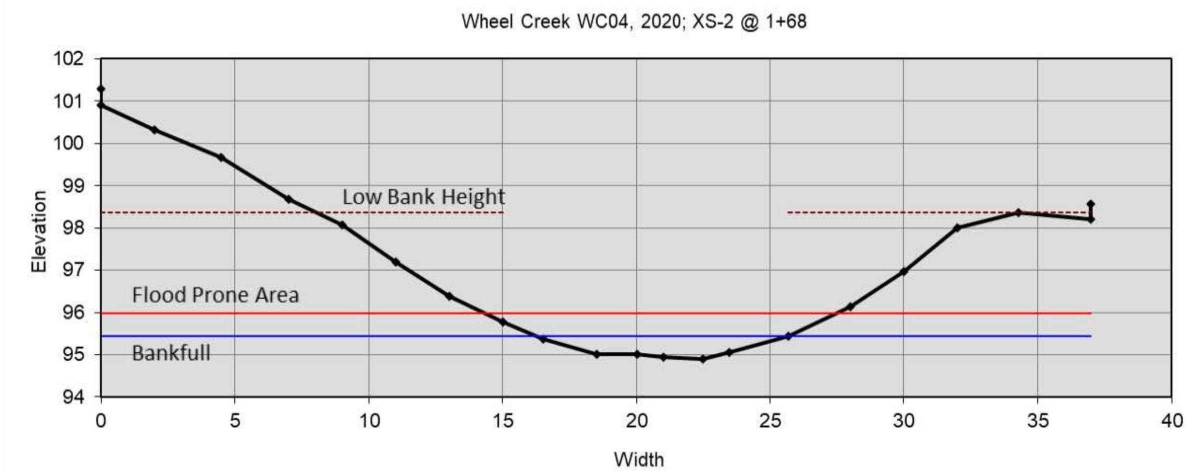
Bankfull Dimensions		Flood Dimensions		Materials	
7.6	x-section area (ft.sq.)	16.8	W flood prone area (ft)	36	D50 Riffle (mm)
10.7	width (ft)	1.6	entrenchment ratio	77	D84 Riffle (mm)
0.7	mean depth (ft)	3.4	low bank height (ft)	32	threshold grain size (mm):
1.0	max depth (ft)	3.4	low bank height ratio		
11.5	wetted parimeter (ft)				
0.7	hyd radi (ft)				
15.2	width-depth ratio				



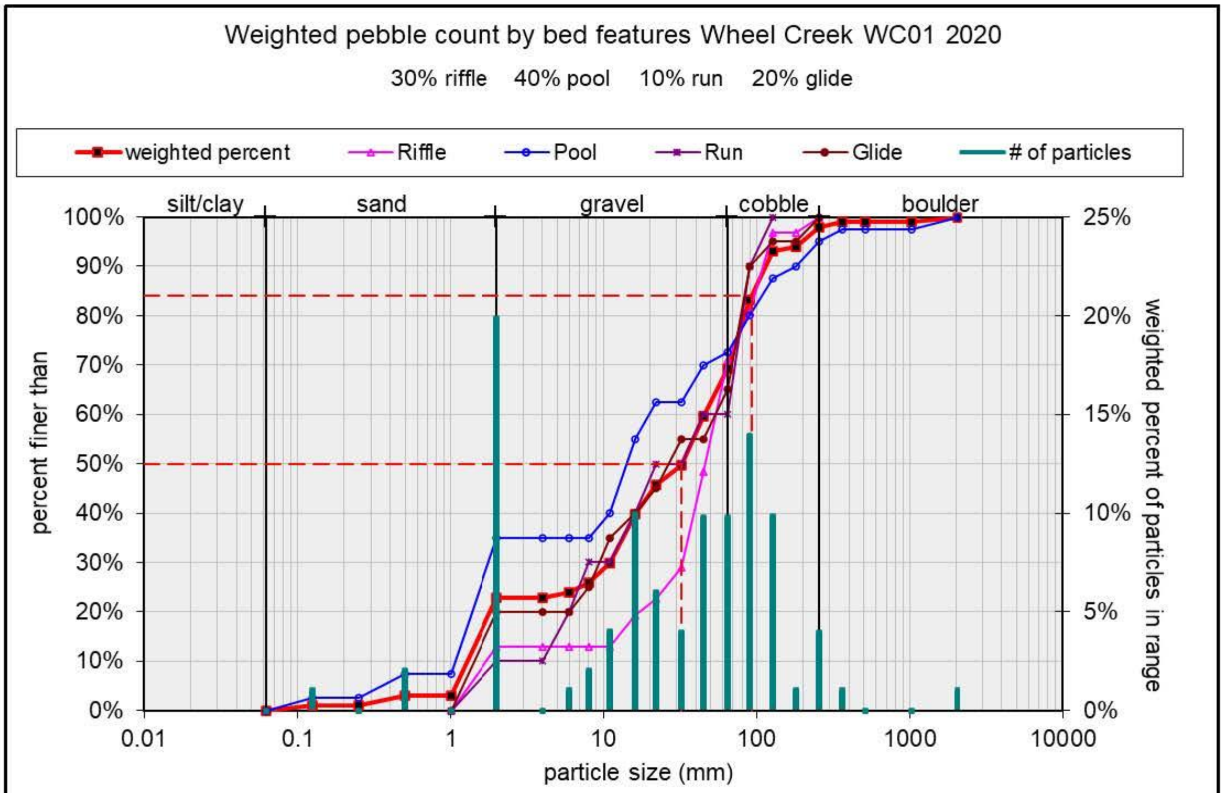
Bankfull Dimensions		Flood Dimensions		Materials	
16.2	x-section area (ft.sq.)	34.7	W flood prone area (ft)	36	D50 Riffle (mm)
13.0	width (ft)	2.7	entrenchment ratio	77	D84 Riffle (mm)
1.3	mean depth (ft)	3.2	low bank height (ft)	57	threshold grain size (mm):
2.2	max depth (ft)	1.5	low bank height ratio		
13.9	wetted parimeter (ft)				
1.2	hyd radi (ft)				
10.4	width-depth ratio				



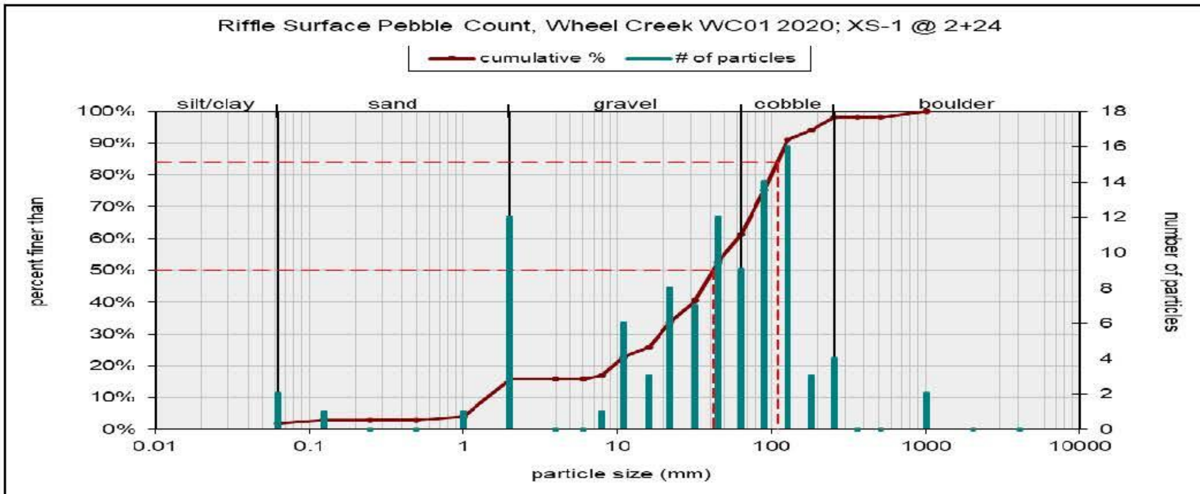
Bankfull Dimensions		Flood Dimensions		Materials	
5.8	x-section area (ft.sq.)	32.9	W flood prone area (ft)	20	D50 Bed (mm)
7.8	width (ft)	4.2	entrenchment ratio	58	D84 Bed (mm)
0.7	mean depth (ft)	4.2	low bank height (ft)	34	threshold grain size (mm):
1.4	max depth (ft)	3.0	low bank height ratio		
8.5	wetted parimeter (ft)				
0.7	hyd radi (ft)				
10.5	width-depth ratio				



Bankfull Dimensions		Flood Dimensions		Materials	
3.3	x-section area (ft.sq.)	13.2	W flood prone area (ft)	20	D50 Bed (mm)
9.4	width (ft)	1.4	entrenchment ratio	58	D84 Bed (mm)
0.3	mean depth (ft)	3.5	low bank height (ft)	22	threshold grain size (mm):
0.5	max depth (ft)	6.4	low bank height ratio		
9.5	wetted parimeter (ft)				
0.3	hyd radi (ft)				
27.4	width-depth ratio				



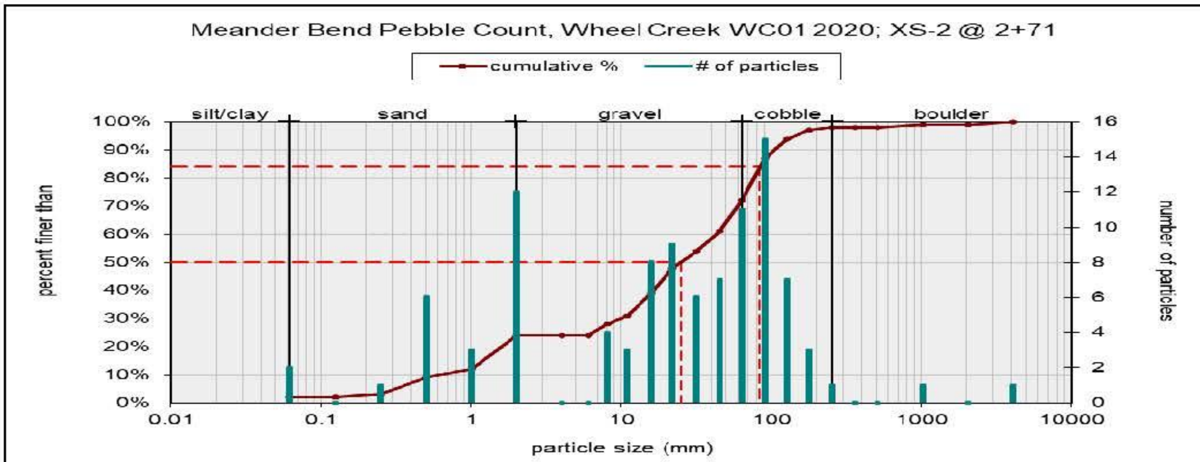
Size (mm)			Size Distribution			Type	
D16	1.6		mean	12.2		silt/clay	0%
D35	13		dispersion	11.5		sand	23%
D50	32		skewness	-0.32		gravel	46%
D65	55					cobble	29%
D84	93					boulder	2%
D95	200						



Size (mm)	
D16	6.3
D35	24
D50	42
D65	70
D84	110
D95	200

Size Distribution	
mean	26.3
dispersion	4.6
skewness	-0.18

Type	
silt/clay	2%
sand	14%
gravel	46%
cobble	37%
boulder	2%



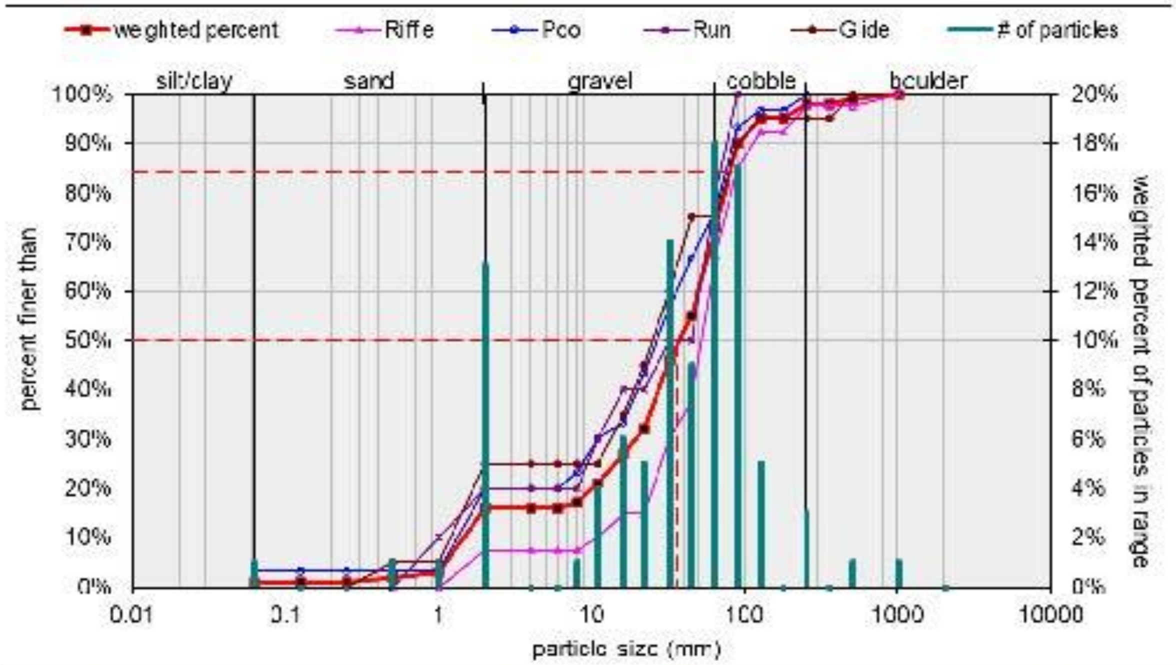
Size (mm)		
D16	1.3	3.4
D35	13	12
D50	25	17
D65	51	20
D84	84	29
D95	140	39

Size Distribution	
mean	10.4
dispersion	11.3
skewness	-0.28

Type	
silt/clay	2%
sand	22%
gravel	48%
cobble	26%
boulder	2%

Weighted pebble count by bed features Wheel Creek WC02 2020

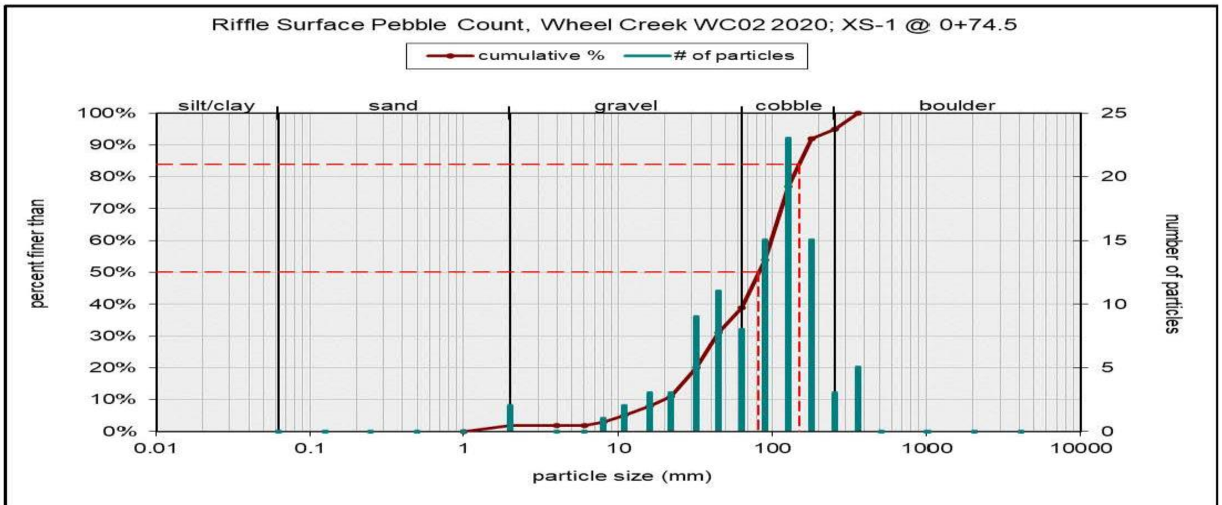
40% riffle 30% pool 10% run 20% glide



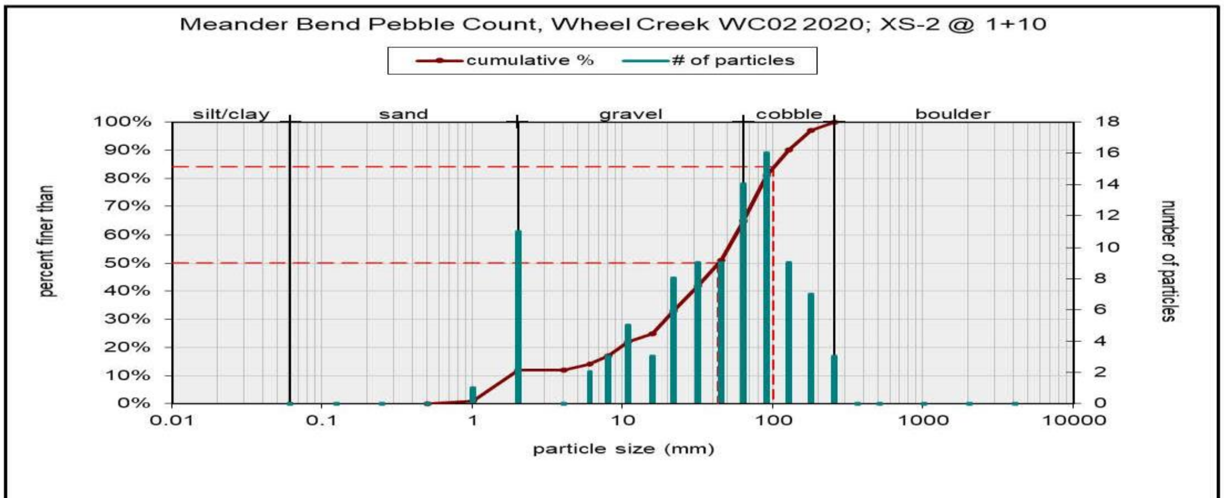
Size (mm)	
D16	6
D35	24
D50	37
D65	55
D84	80
D95	#N/A

Size Distribution	
mean	21.9
dispersion	4.2
skewness	-0.21

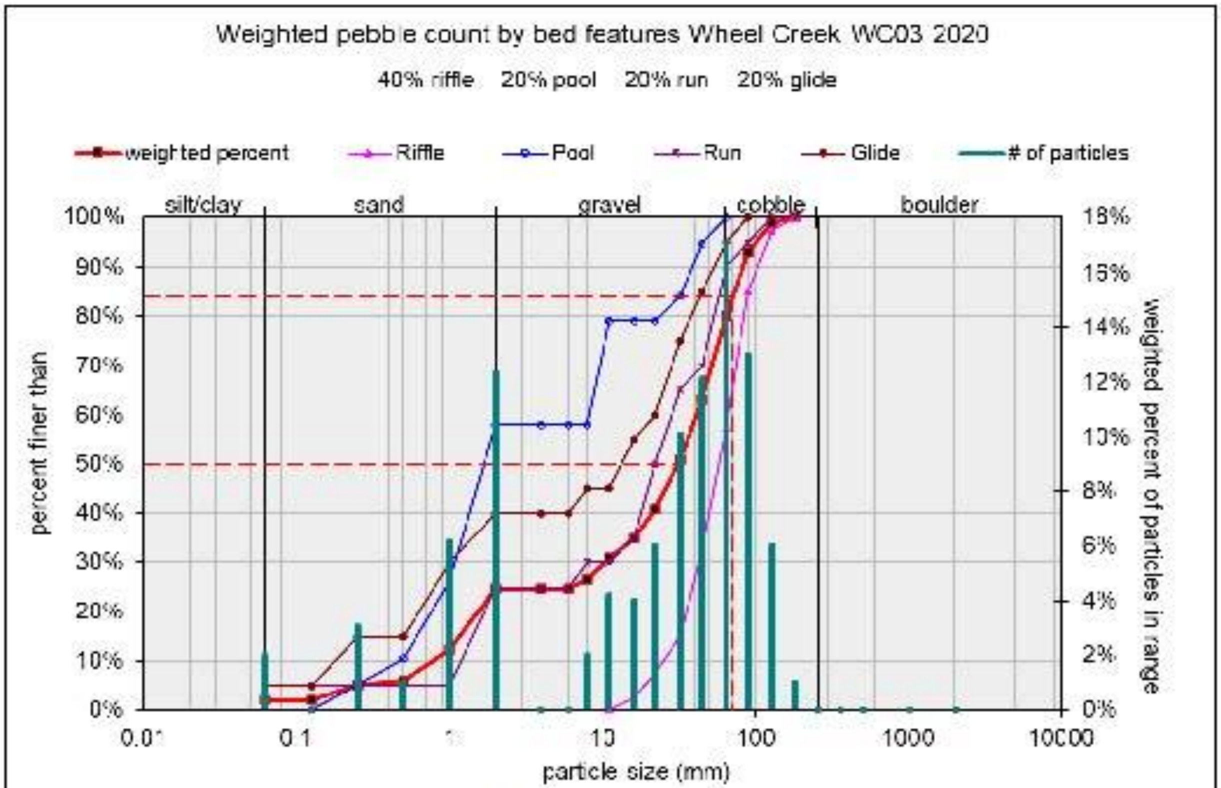
Type	
silt/clay	1%
sand	15%
gravel	57%
cobble	25%
boulder	2%



Size (mm)		Size Distribution		Type	
D16	27	mean	63.6	silt/clay	0%
D35	54	dispersion	2.4	sand	2%
D50	82	skewness	-0.13	gravel	37%
D65	110			cobble	56%
D84	150			boulder	5%
D95	260				



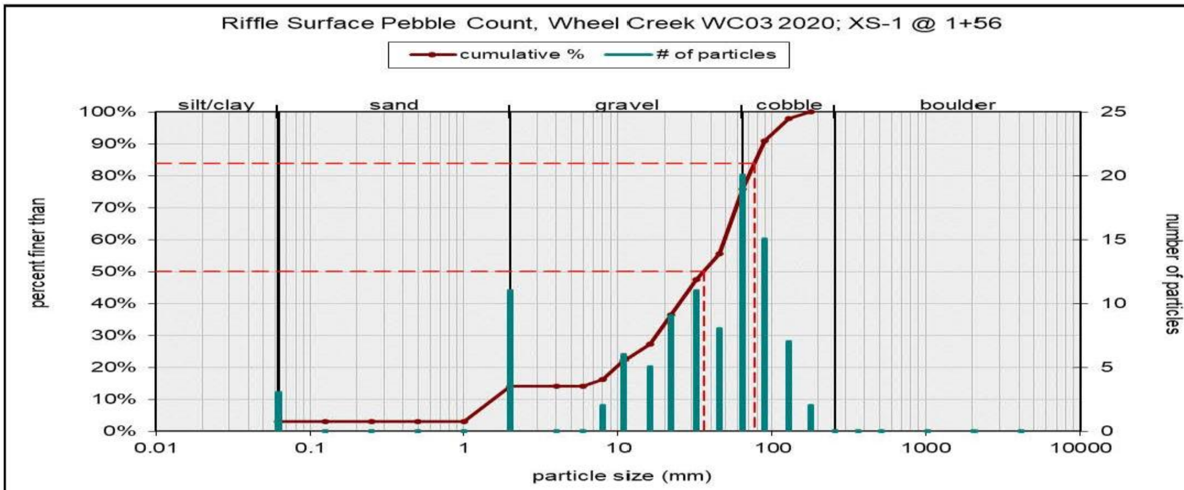
Size (mm)			Size Distribution		Type	
D16	7.3	3.4	mean	27.0	silt/clay	0%
D35	24	12	dispersion	4.1	sand	12%
D50	43	17	skewness	-0.19	gravel	53%
D65	64	20			cobble	35%
D84	100	29			boulder	0%
D95	160	39				



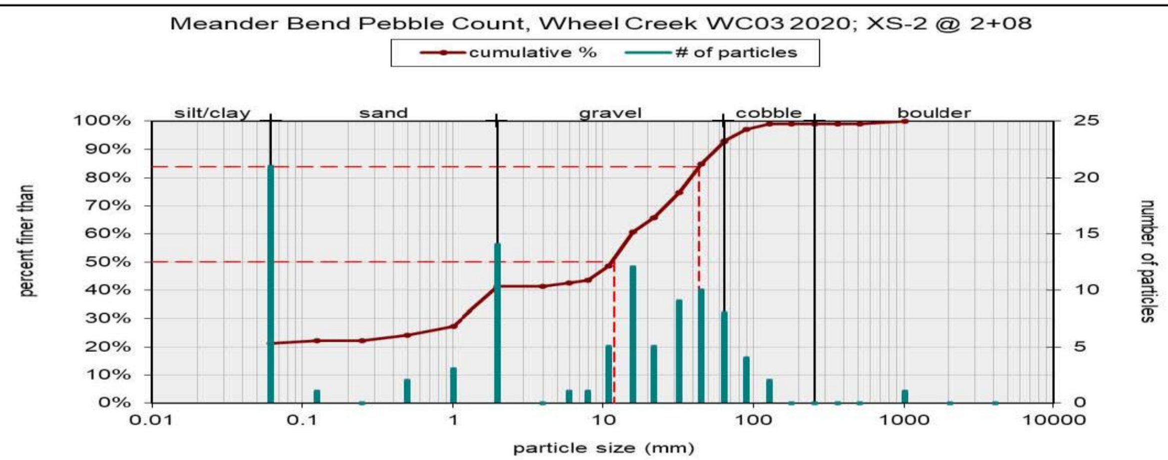
Size (mm)	
D16	1.2
D35	16
D50	31
D65	47
D84	71
D95	100

Size Distribution	
mean	9.2
dispersion	14.1
skewness	-0.40

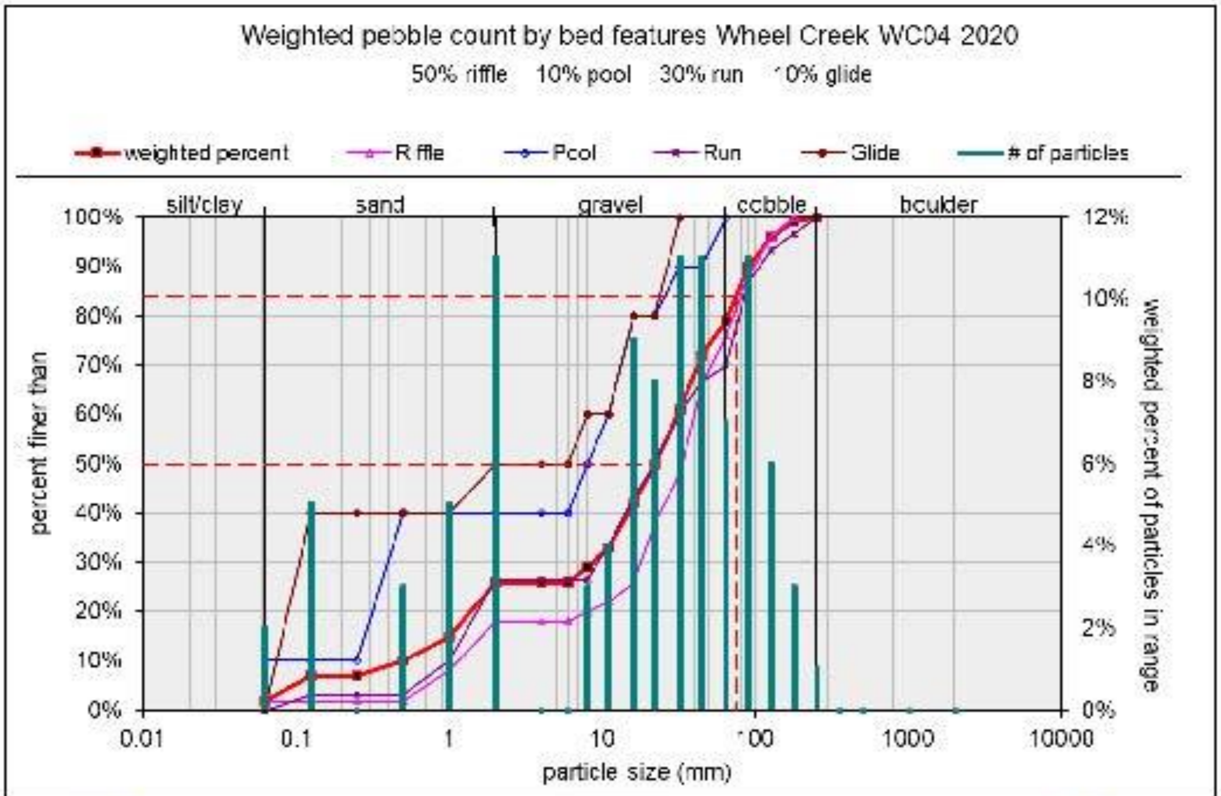
Type	
silt/clay	2%
sand	22%
gravel	54%
cobble	20%
boulder	0%



Size (mm)		Size Distribution		Type	
D16	7.8	mean	24.5	silt/clay	3%
D35	21	dispersion	3.4	sand	11%
D50	36	skewness	-0.17	gravel	61%
D65	53			cobble	24%
D84	77			boulder	0%
D95	110				



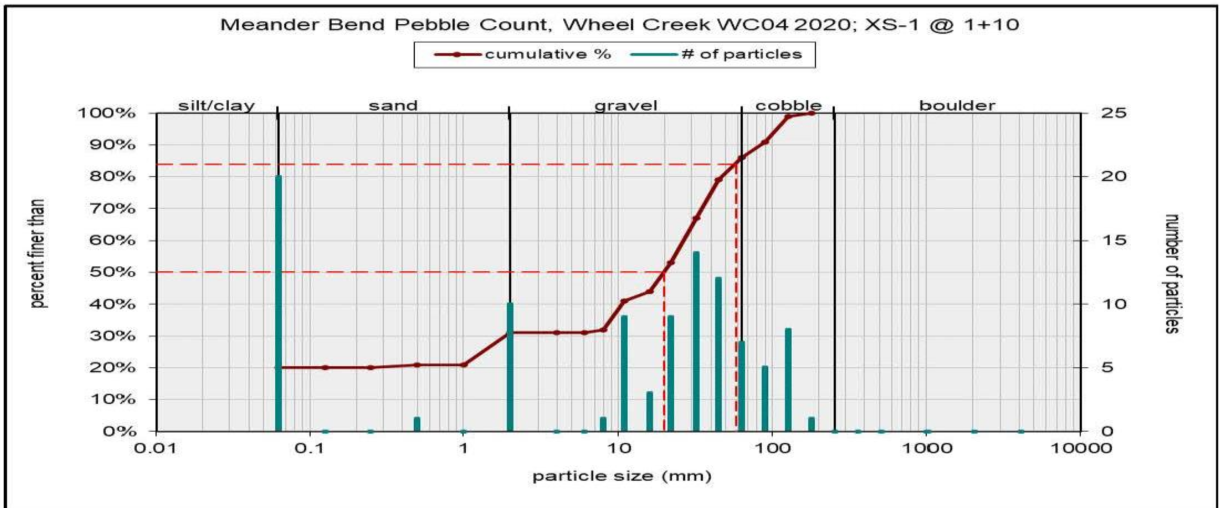
Size (mm)			Size Distribution		Type	
D16	0.062	3.4	mean	1.7	silt/clay	21%
D35	1.5	12	dispersion	98.6	sand	20%
D50	12	17	skewness	-0.51	gravel	51%
D65	21	20			cobble	6%
D84	44	29			boulder	1%
D95	76	39				



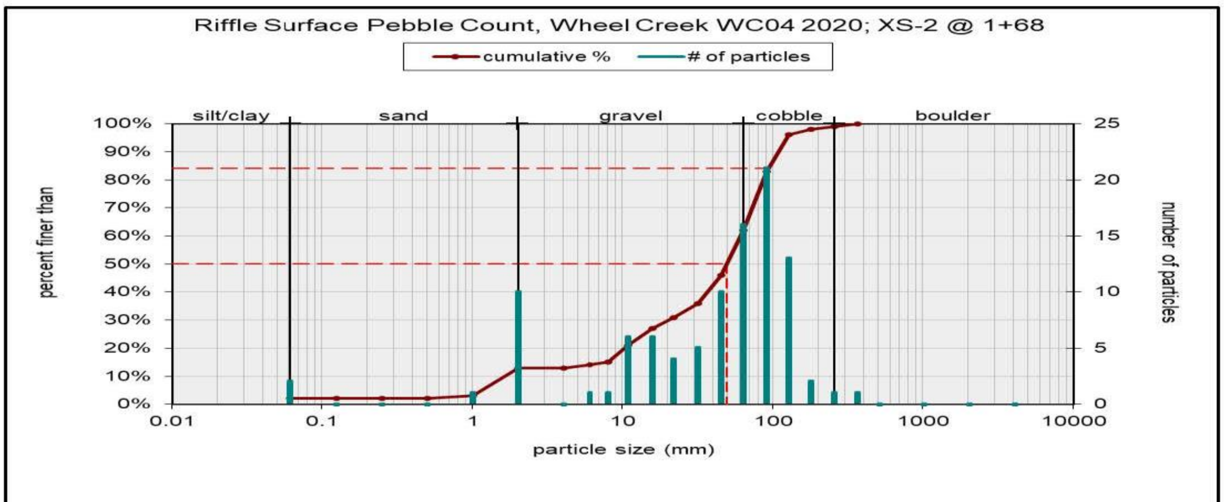
Size (mm)	
D16	1.1
D35	12
D50	22
D65	36
D84	75
D95	120

Size Distribution	
mean	9.1
dispersion	11.7
skewness	-0.28

Type	
silt/clay	2%
sand	24%
gravel	53%
cobble	21%
boulder	0%



Size (mm)		Size Distribution		Type	
D16	0.062	mean	1.9	silt/clay	20%
D35	8.9	dispersion	162.7	sand	11%
D50	20	skewness	-0.59	gravel	55%
D65	30			cobble	14%
D84	58			boulder	0%
D95	110				



Size (mm)			Size Distribution		Type	
D16	8.4	3.4	mean	27.8	silt/clay	2%
D35	30	12	dispersion	3.9	sand	11%
D50	49	17	skewness	-0.24	gravel	49%
D65	67	20			cobble	37%
D84	92	29			boulder	1%
D95	120	39				

APPENDIX C

ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Pre-Restoration Year 1 – Year 4 (2010-2015) and Post-Restoration Years 1 – 4 (2017-2020)

Reach	Year	Length (ft)	Slope	Proportion of Features: Riffle	Run	Pool	Glide
WC01*	2010	400	2.3%	43.6%	11.3%	22.1%	23.0%
	2012	420	2.2%	54.6%	7.3%	29.2%	8.9%
	2013	420	2.2%	55.7%	8.2%	23.8%	12.3%
	2015	420	2.2%	50.9%	24.8%	14.1%	10.2%
	2017	*490*	*2.6%*	*47.5%*	*7.6%*	*36.6%*	*8.3%*
	2018	*490*	*2.7%*	*48.5%*	*8.6%*	*28.6%*	*14.4%*
	2019	*490*	*2.7%*	*46.6%*	*12.7%*	*29.4%*	*11.3%*
	2020	*490*	*2.7%*	*35.6%*	*17.2%*	*27.8%*	*19.4%*
WC02*	2010	350	2.3%	53.4%	0%	46.6%	0%
	2012	350	2.4%	33.7%	11.0%	38.6%	16.7%
	2013	350	2.3%	48.1%	12.6%	26.3%	13.0%
	2015	350	2.2%	49.4%	25.1%	13.4%	12.1%
	2017	*321.5*	*2.3%*	*57.3%*	*6.3%*	*28.5%*	*10.5%*
	2018	*320*	*2.3%*	*45.0%*	*15.3%*	*28.1%*	*11.6%*
	2019	*320*	*2.2%*	*47.6%*	*13.9%*	*26.4%*	*12.1%*
	2020	*340*	*2.2%*	*49.7%*	*9.3%*	*23.6%*	*17.4%*
WC03	2010	300	1.7%	34.4%	0%	65.6%	0%
	2012	300	1.8%	24.0%	8.5%	54.9%	12.6%
	2013	306.3	1.6%	37.2%	15.9%	30.4%	16.5%
	2015	306	1.7%	32.0%	9.5%	34.0%	24.5%
	2017	*306*	*1.7%*	*52.4%*	*13.6%*	*23.5%*	*10.5%*
	2018	*309*	*1.7%*	*48.4%*	*14.3%*	*29.4%*	*7.8%*
	2019	*308*	*1.8%*	*46.0%*	*16.3%*	*28.1%*	*9.6%*
	2020	*308*	*1.8%*	*42.6%*	*7.4%*	*35.4%*	*14.6%*
WC04	2010	300	3.5%	60.0%	0%	40.0%	0%
	2012	300	3.4%	41.3%	16.2%	30.3%	12.2%
	2013	300	3.4%	46.5%	11.0%	27.9%	14.6%
	2015	300	3.4%	50.3%	21.7%	19.0%	9.0%
	2017	*300*	*3.5%*	*48.2%*	*24.3%*	*14.0%*	*13.5%*
	2018	*300*	*3.7%*	*67.5%*	*13.0%*	*13.9%*	*5.2%*
	2019	*300*	*3.3%*	*70.0%*	*8.7%*	*13.3%*	*8.0%*
	2020	*300*	*3.5%*	*57.2%*	*18.3%*	*16.2%*	*8.3%*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

Table C-2. Comparisons of Cross-sectional Survey Analyses Pre-Restoration Years 1 – 4 (2010 – 2015) and Post-Restoration Years 1 – 4 (2017 – 2020)

Reach	Year	Station	Feature	Bankfull Width (ft)	Mean Depth (ft)	Width/ Depth Ratio	Entrench-ment Ratio	Bankfull Area (ft^2)	Top of Bank Area (ft^2)
WC01*	2010	2+30	Crossover Riffle	21.1	1.0	22.2	1.5	20.1	73.0
	2012	2+30	Crossover Riffle	21.3	1.1	18.6	1.5	24.5	78.1
	2013	2+29	Crossover Riffle	21.6	1.1	20.2	1.5	23.2	66.9
	2015	2+29	Crossover Riffle	21.0	1.0	21.6	1.5	20.5	74.8
	2017	*2+24*	*Crossover Riffle*	*20.7*	*0.8*	*26.8*	*1.7*	*16.0*	*164.4*
	2018	*2+24*	*Crossover Riffle*	*21.7*	*1.0*	*21.9*	*1.8*	*21.6*	*169.6*
	2019	*2+24*	*Crossover Riffle*	*28.8*	*0.7*	*41.2*	*1.4*	*20.1*	*161.7*
	2020	*2+24*	*Crossover Riffle*	*24.5*	*0.9*	*27.0*	*1.7*	*22.1*	*148.4*
	2010	2+95	Meander/Riffle	22.1	0.8	26.0	1.5	18.8	230.1
	2012	2+95	Meander/Riffle	28.9	0.8	37.5	1.5	22.3	246.9
	2013	2+95	Meander/Riffle	29.0	0.9	34.1	1.5	24.7	212.7
	2015	2+95	Meander/Riffle	29.1	1.2	25.0	1.6	33.8	259.6
	2017	*2+71*	*Meander/Pool*	*21.3*	*2.0*	*10.7*	*1.4*	*42.6*	*269.7*
	2018	*2+71*	*Meander/Pool*	*21.5*	*1.5*	*14.5*	*1.8*	*31.8*	*236.4*
	2019	*2+71*	*Meander/Pool*	*20.3*	*1.5*	*13.5*	*2.0*	*30.6*	*223.0*
	2020	*2+71*	*Meander/Pool*	*13.9*	*1.8*	*7.6*	*2.1*	*25.4*	*144.7*
WC02*	2010	1+37	Crossover Riffle	13.1	0.7	18.4	1.2	9.3	31.6
	2012	1+38	Crossover Riffle	14.3	0.6	24.1	1.2	8.5	37.1
	2013	1+38	Crossover Riffle	14.3	0.7	19.4	1.2	10.6	36.7
	2015	1+38	Crossover Riffle	13.9	0.8	17.9	1.2	10.8	28.4
	2017	*1+10*	*Crossover Riffle*	*11.6*	*0.5*	*24.6*	*1.3*	*5.5*	*38.6*
	2018	*1+10*	*Crossover Riffle*	*13.6*	*0.7*	*20.8*	*1.4*	*8.9*	*56.5*
	2019	*1+10*	*Pool*	*12.6*	*0.7*	*17.4*	*1.3*	*9.1*	*38.4*
	2020	*1+10*	*Pool*	*11.9*	*0.6*	*18.6*	*1.2*	*7.6*	*35.3*
	2010	3+24	Meander/Riffle	16.7	0.9	19.3	1.3	14.5	70.3
	2012	3+24	Meander/Riffle	14.6	0.6	23.8	1.4	9.0	71.7
	2013	3+25.5	Meander/Riffle	15.6	0.7	21.8	1.5	11.1	72.0
	2015	3+24	Meander/Riffle	16.4	0.9	19.1	1.4	14.0	74.6
	2017	*0+74.5*	*Pool*	*13.6*	*1.3*	*10.2*	*1.3*	*18.2*	*49.0*
	2018	*0+74.5*	*Pool*	*11.6*	*0.7*	*16.5*	*1.4*	*8.1*	*43.5*
	2019	*0+74.5*	*Crossover Riffle*	*16.2*	*0.6*	*28.5*	*1.4*	*9.2*	*48.4*
	2020	*0+74.5*	*Crossover Riffle*	*14.8*	*0.4*	*38.1*	*1.3*	*5.7*	*21.8*
WC03	2010	1+55	Crossover Riffle	9.2	0.4	24.1	1.1	3.5	37.5
	2012	1+57	Pool	10.6	1.1	9.8	1.3	11.4	41.3
	2013	1+56	Crossover Riffle	10.1	0.9	11.8	1.2	8.6	38.2
	2015	1+55	Crossover Riffle	9.3	0.7	12.7	1.2	6.8	37.9
	2017	*1+56*	*Crossover Riffle*	*7.3*	*0.9*	*8.6*	*1.7*	*7.3*	*35.0*
	2018	*1+56*	*Crossover Riffle*	*10.0*	*1.1*	*9.4*	*1.3*	*10.7*	*41.6*
	2019	*1+56*	*Crossover Riffle*	*10.4*	*0.9*	*11.7*	*1.3*	*9.2*	*42.3*
	2020	*1+56*	*Crossover Riffle*	*10.7*	*0.7*	*15.2*	*1.6*	*7.6*	*40.5*
	2010	2+07	Meander/Pool	7.2	0.5	13.0	1.9	3.9	43.8
	2012	2+08	Meander/Pool	10.2	1.2	8.4	2.5	12.5	56.2
	2013	2+12	Meander/Pool	9.7	1.0	10.0	2.7	9.4	55.0
	2015	2+07	Meander/Pool	9.9	1.1	9.4	2.8	10.5	61.4
	2017	*2+08*	*Meander/Run*	*9.8*	*0.9*	*12.2*	*2.7*	*9.8*	*61.5*
	2018	*2+08*	*Meander/Run*	*11.5*	*0.6*	*18.3*	*2.3*	*7.2*	*61.8*

Table C-2. (Continued)									
Reach	**Year**	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC03	*2019*	*2+08*	*Meander/Run*	*11.6*	*0.7*	*15.9*	*1.6*	*8.5*	*62.6*
	2020	*2+08*	*Meander/Run*	13.0	1.3	*10.4*	*2.7*	*16.2*	*32.1*
WC04	2010	1+08	Meander/Riffle	4.3	0.4	9.8	4.3	1.9	92.5
	2012	1+08	Meander/Pool	6.7	0.6	11.4	3.9	4.0	95.9
	2013	1+08	Meander/Pool	13.0	0.6	23.5	2.2	7.2	99.9
	2015	1+08	Meander/Pool	13.6	0.6	24.0	2.3	7.7	102.8
	2017	*1+10*	*Meander/Pool*	*20.6*	*0.4*	*51.3*	*1.5*	*8.3*	*99.8*
	2018	*1+10*	*Meander/Pool*	*6.8*	*0.6*	*13.6*	*3.4*	*4.5*	*93.4*
	2019	*1+10*	*Meander/Pool*	*11.6*	*0.4*	*28.8*	*2.7*	*4.7*	*90.7*
	2020	*1+10*	*Meander/Pool*	*7.8*	*0.7*	10.5	4.2	5.8	*90.9*
	2010	1+68	Crossover Riffle	8.9	0.4	24.0	1.4	3.3	55.9
	2012	1+68	Crossover Riffle	9.2	0.5	18.9	1.5	4.4	57.8
	2013	1+68	Crossover Riffle	10.4	0.5	20.4	1.4	5.3	56.3
	2015	1+68	Crossover Riffle	11.1	0.6	17.4	1.6	7.1	55.6
	2017	*1+68*	*Crossover Riffle*	*10.4*	*0.5*	*22.3*	*1.4*	*4.8*	*54.8*
	2018	*1+68*	*Crossover Riffle*	*9.2*	*0.3*	*28.8*	*1.3*	*3.0*	*55.4*
	2019	*1+68*	*Crossover Riffle*	*9.7*	*0.4*	*24.1*	*1.4*	*3.9*	*56.0*
	2020	*1+68*	*Crossover Riffle*	*9.4*	*0.3*	*27.4*	*1.4*	*3.3*	*55.7*
*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)									

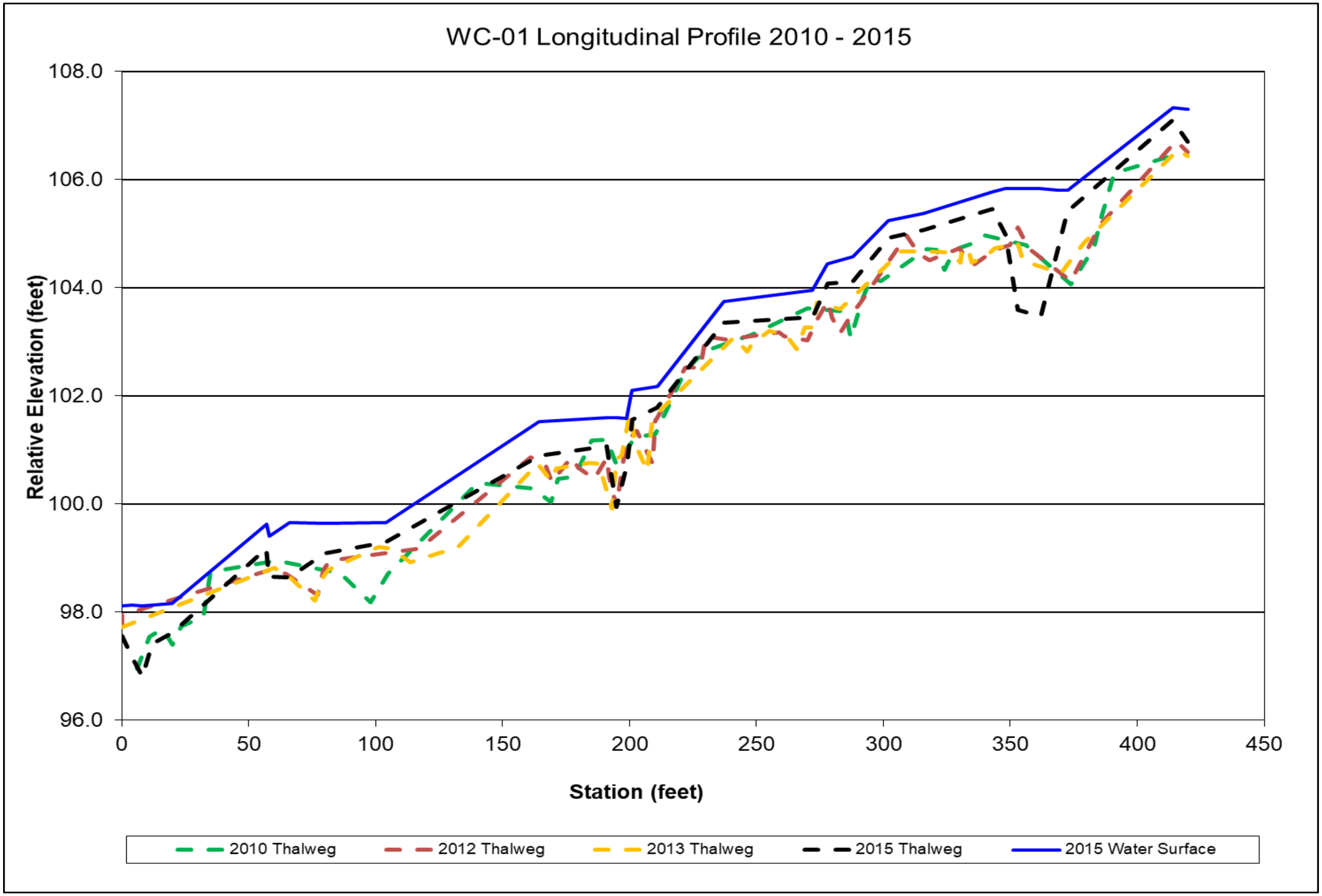

Figure C-1. WC-01 Longitudinal Profile (Pre-Restoration)

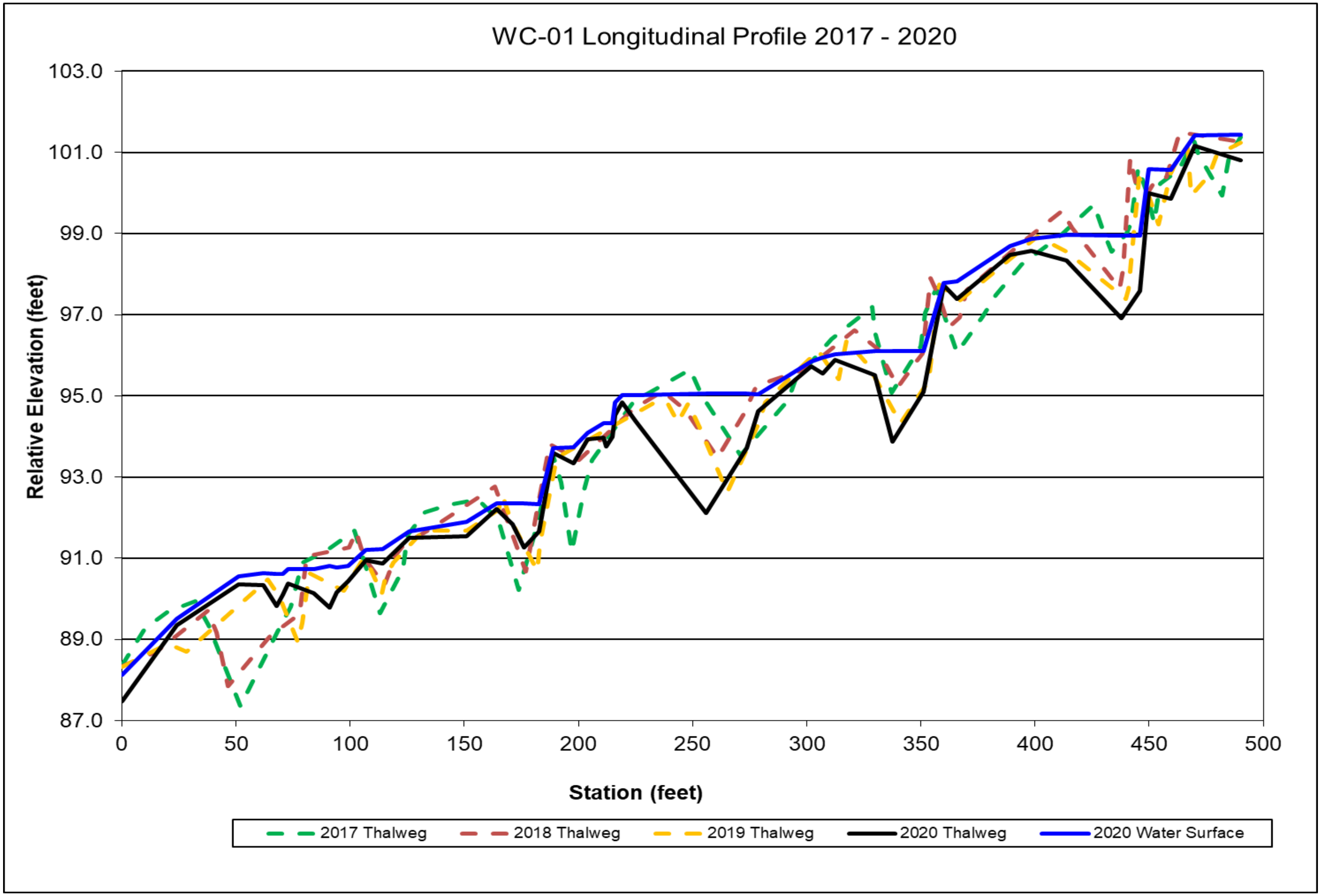

Figure C-2. WC-01 Longitudinal Profile (Post-Restoration)

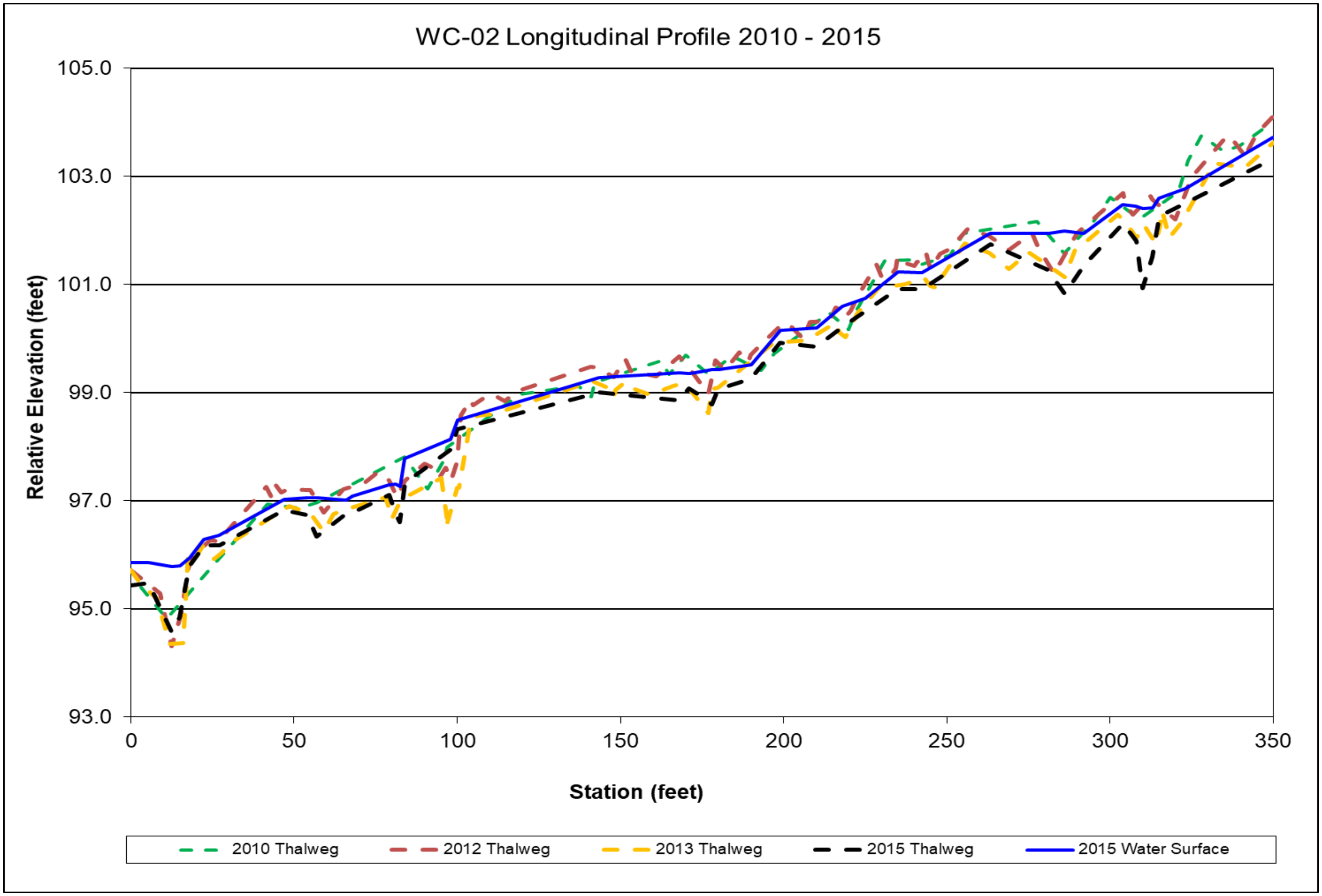

Figure C-3. WC-02 Longitudinal Profile (Pre-Restoration)

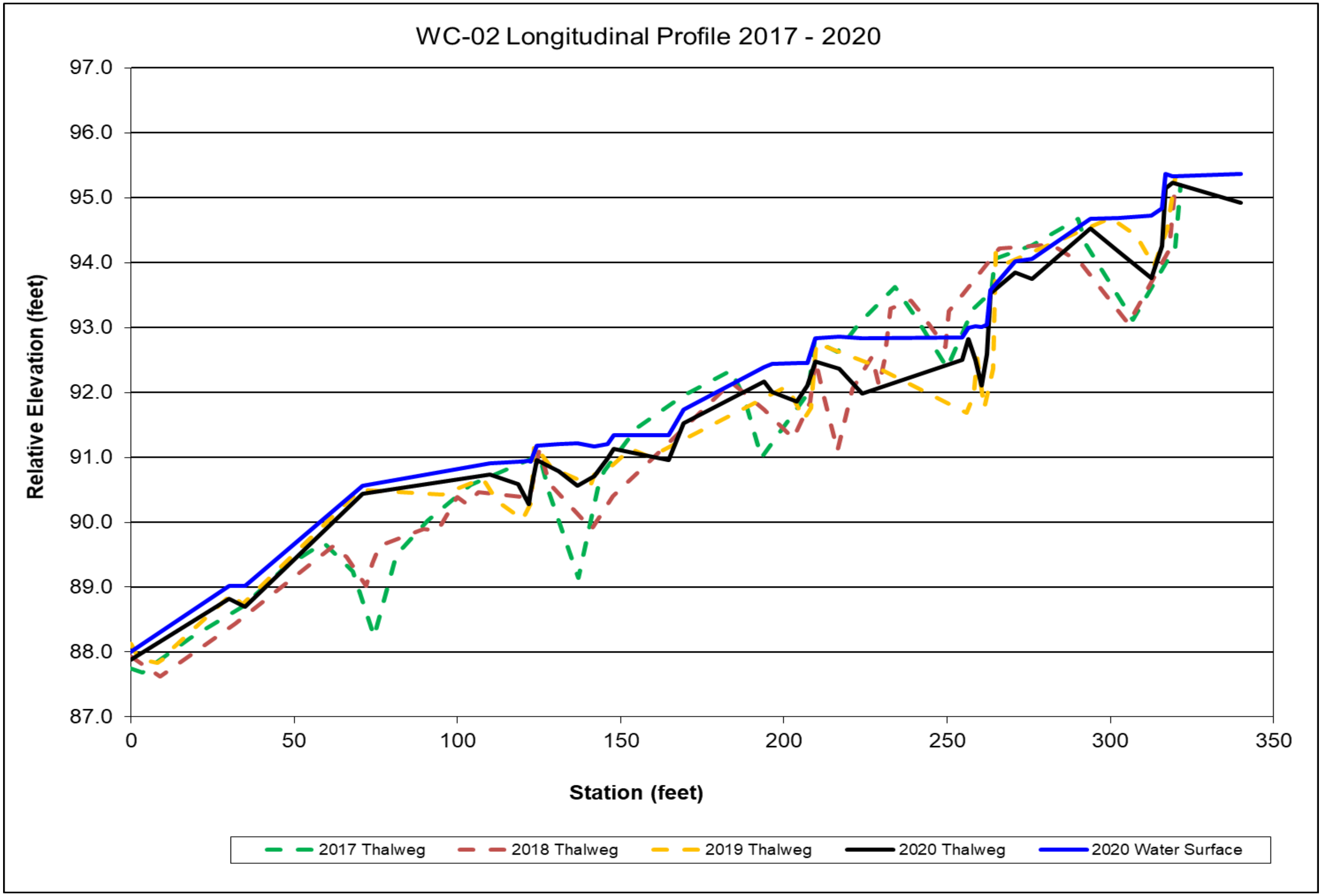

Figure C-4. WC-02 Longitudinal Profile (Post-Restoration)

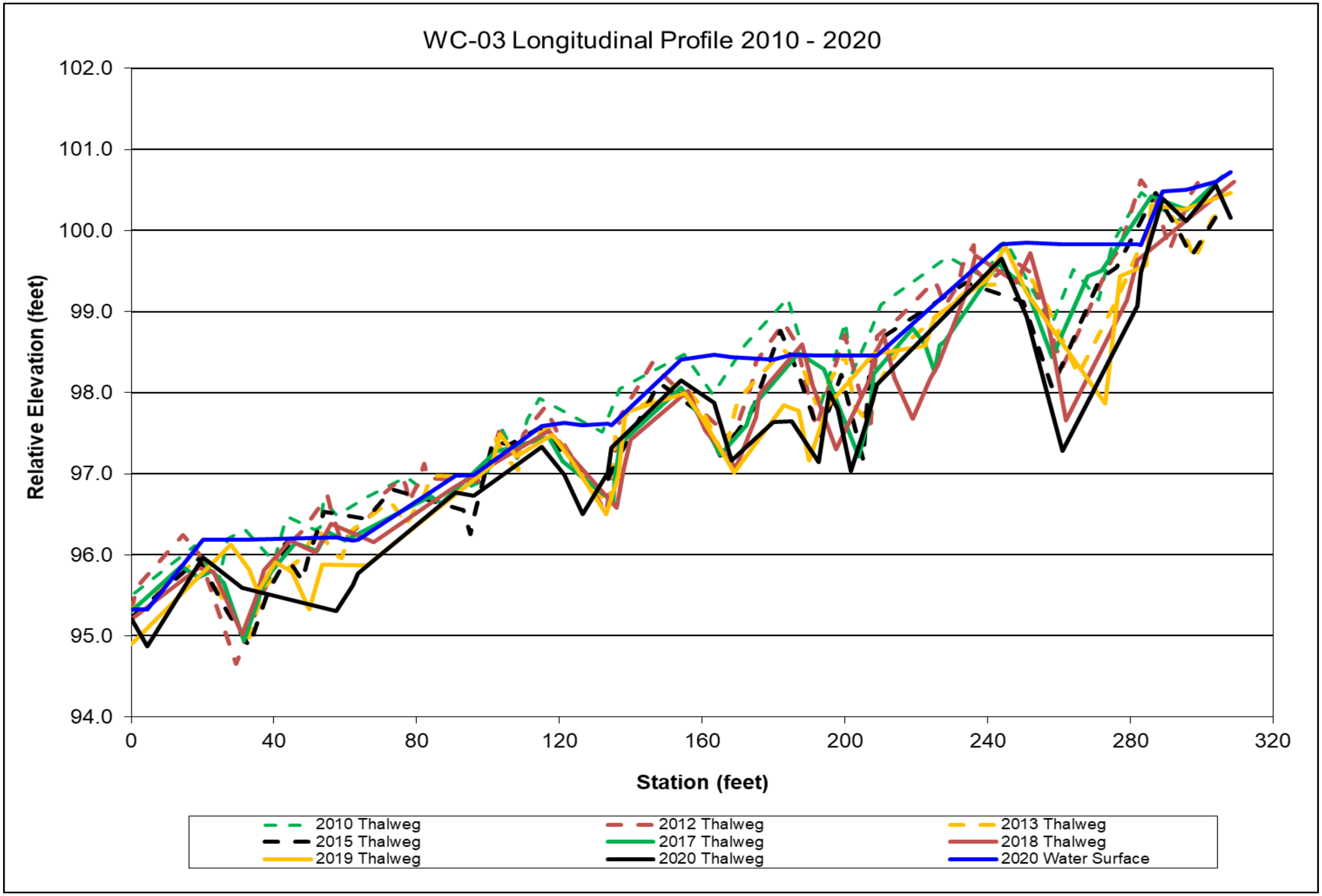

Figure C-5. WC-03 Longitudinal Profile (Pre- and Post-Restoration)

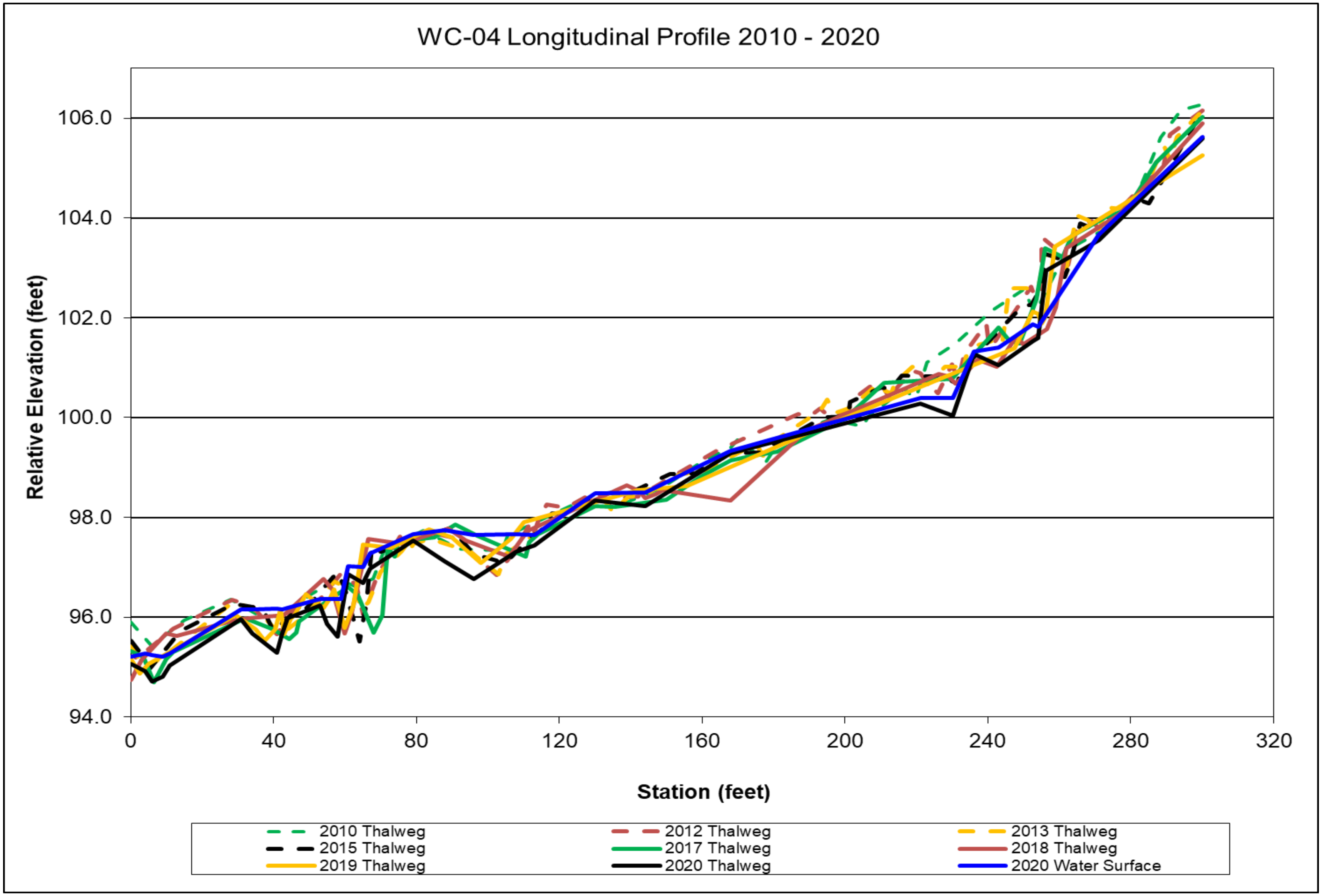

Figure C-6. WC-04 Longitudinal Profile (Pre- and Post-Restoration)

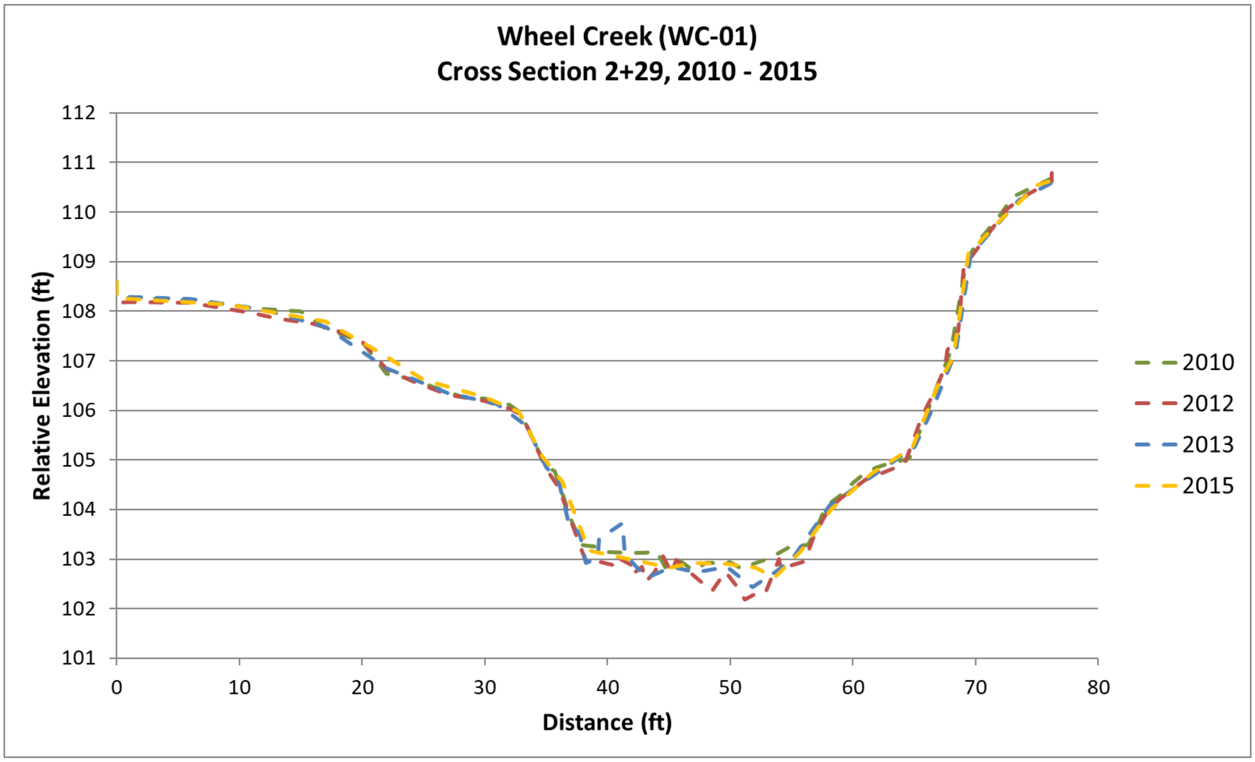

Figure C-7. WC01 Cross-section 1 (Pre-Restoration)

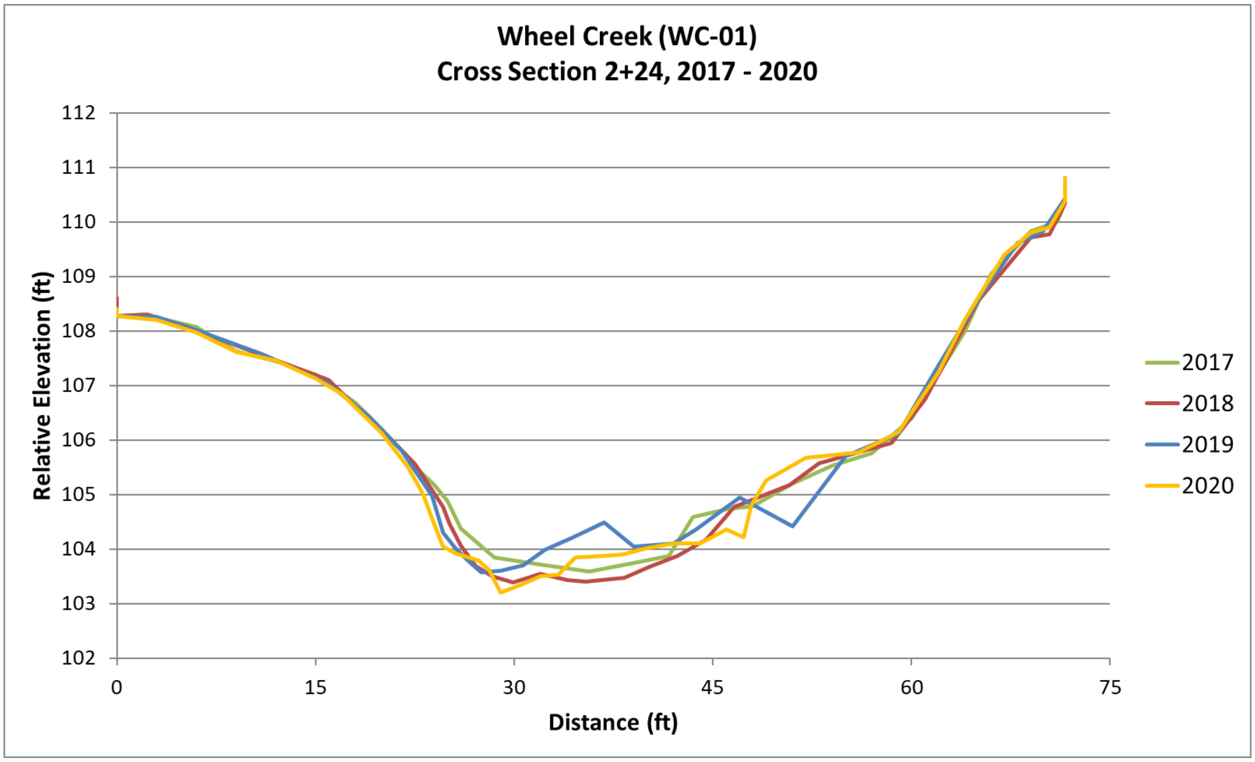

Figure C-8. WC01 Cross-section 1 (Post-Restoration)

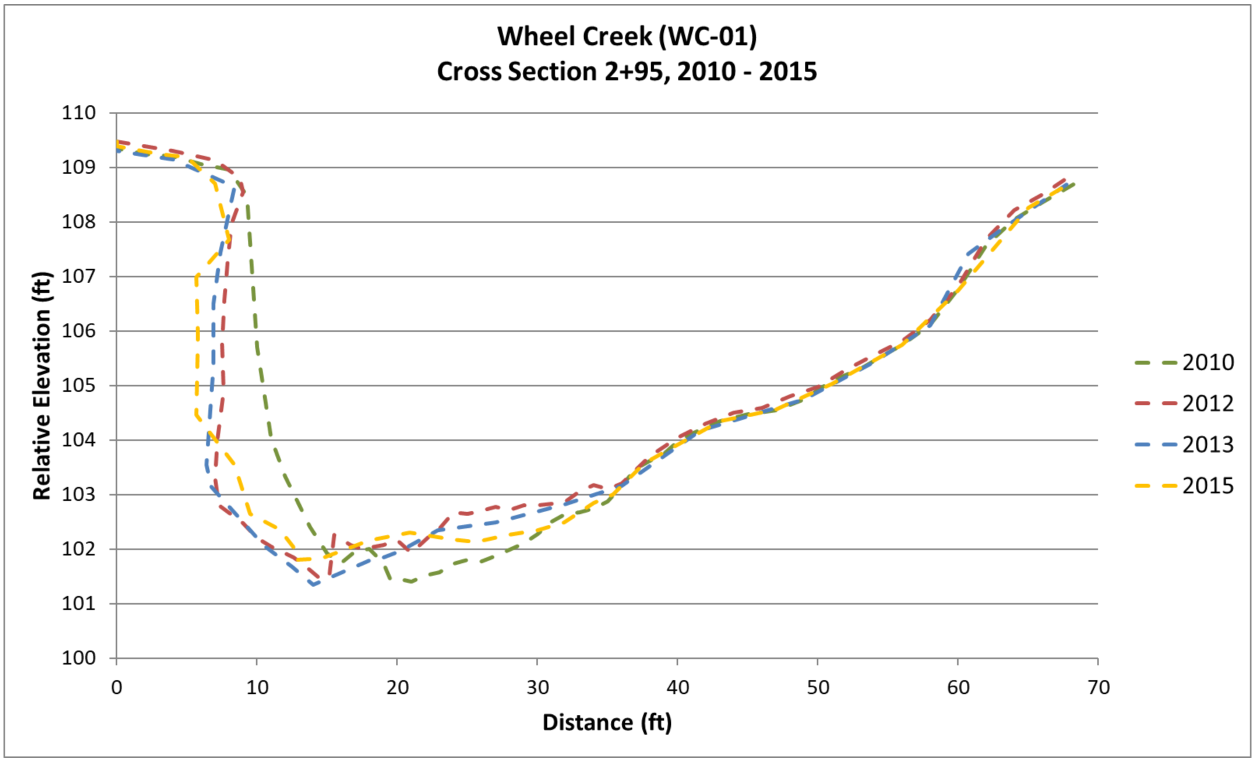

Figure C-9. WC01 Cross-section 2 (Pre-Restoration)

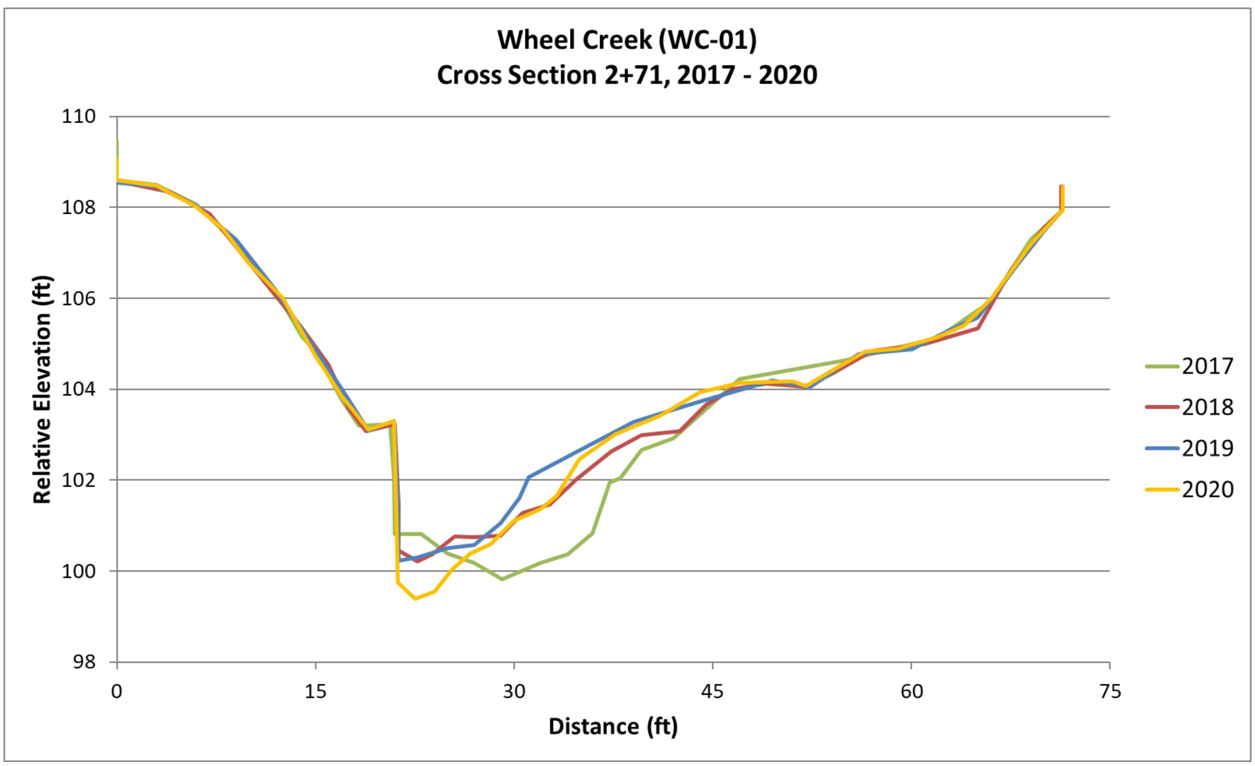

Figure C-10. WC01 Cross-section 2 (Post-Restoration)

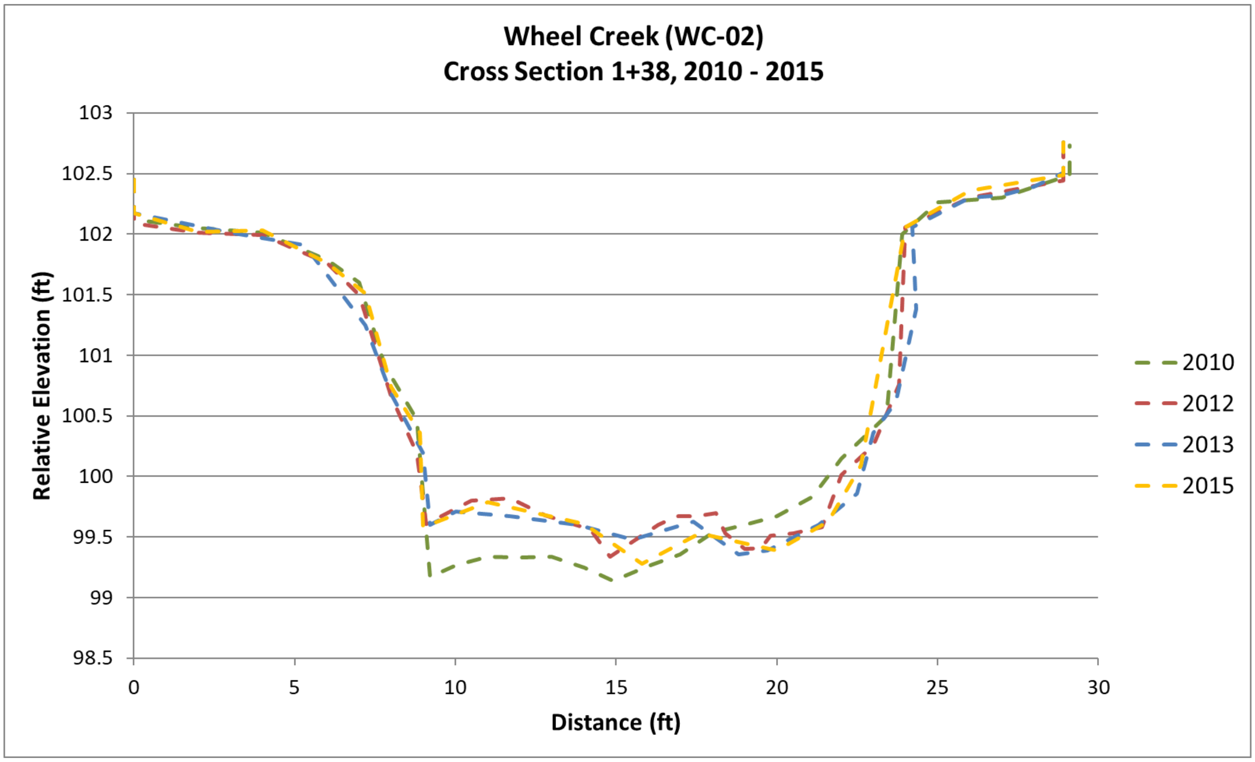

Figure C-11. WC02 Cross-section 1 (Pre-Restoration)

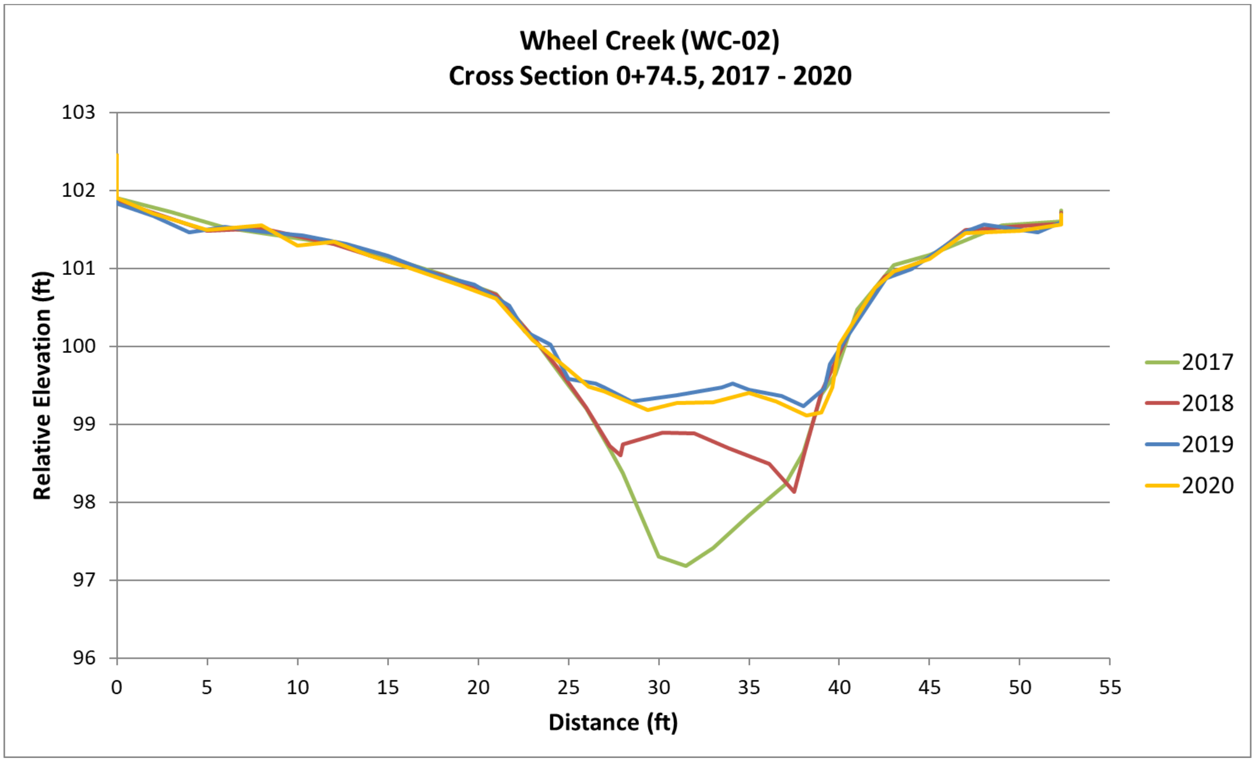

Figure C-12. WC02 Cross-section 1 (Post-Restoration)

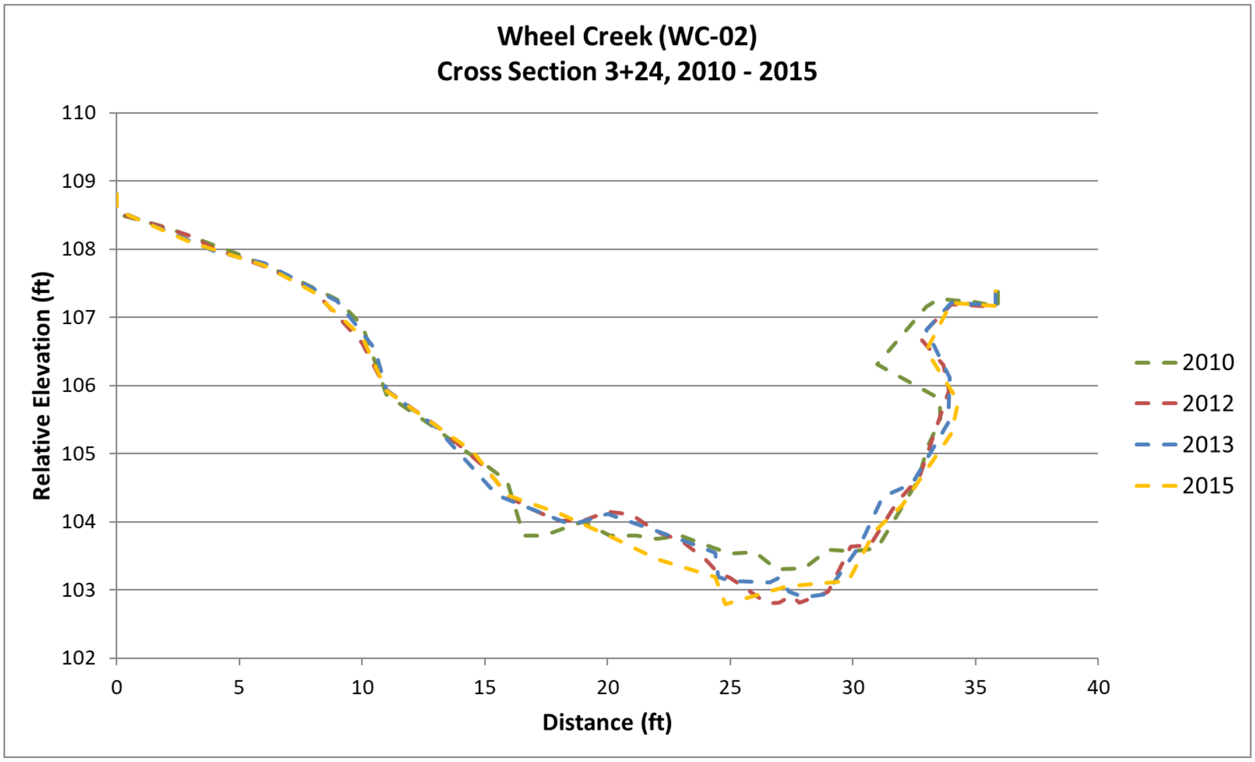

Figure C-13. WC02 Cross-section 2 (Pre-Restoration)

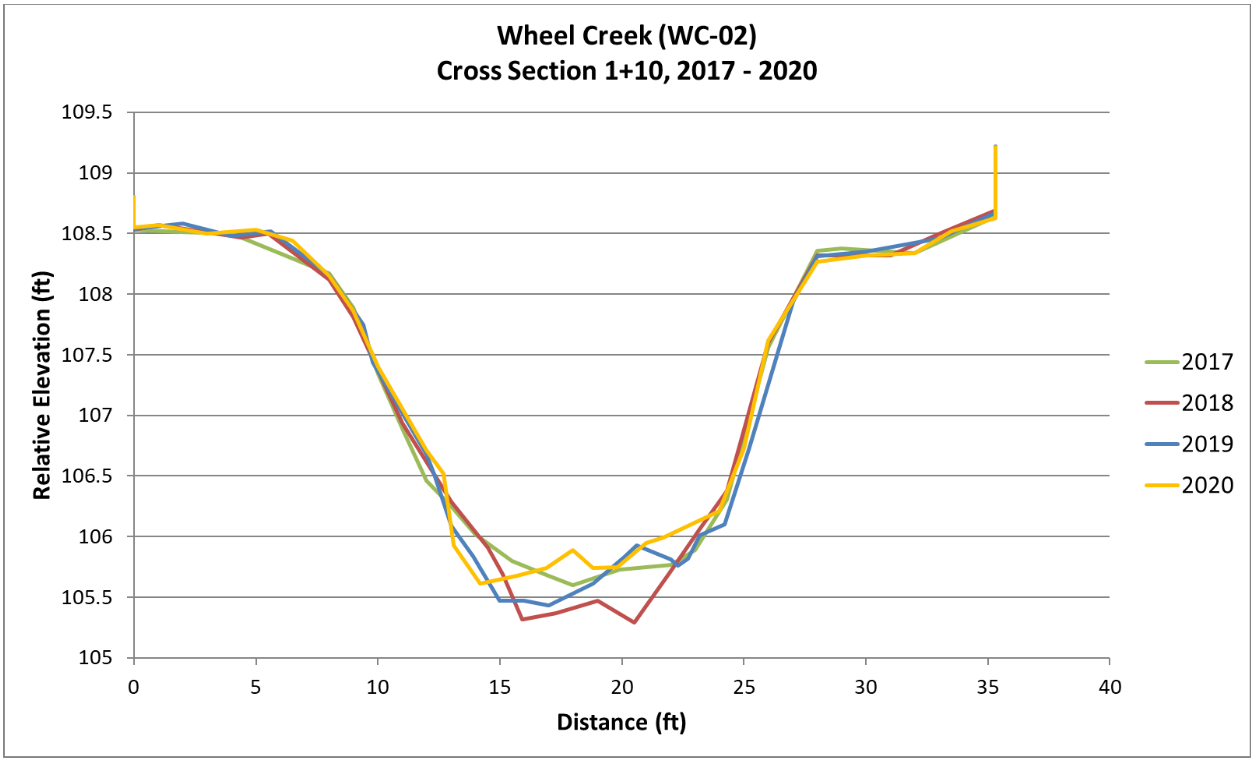

Figure C-14. WC02 Cross-section 2 (Post-Restoration)

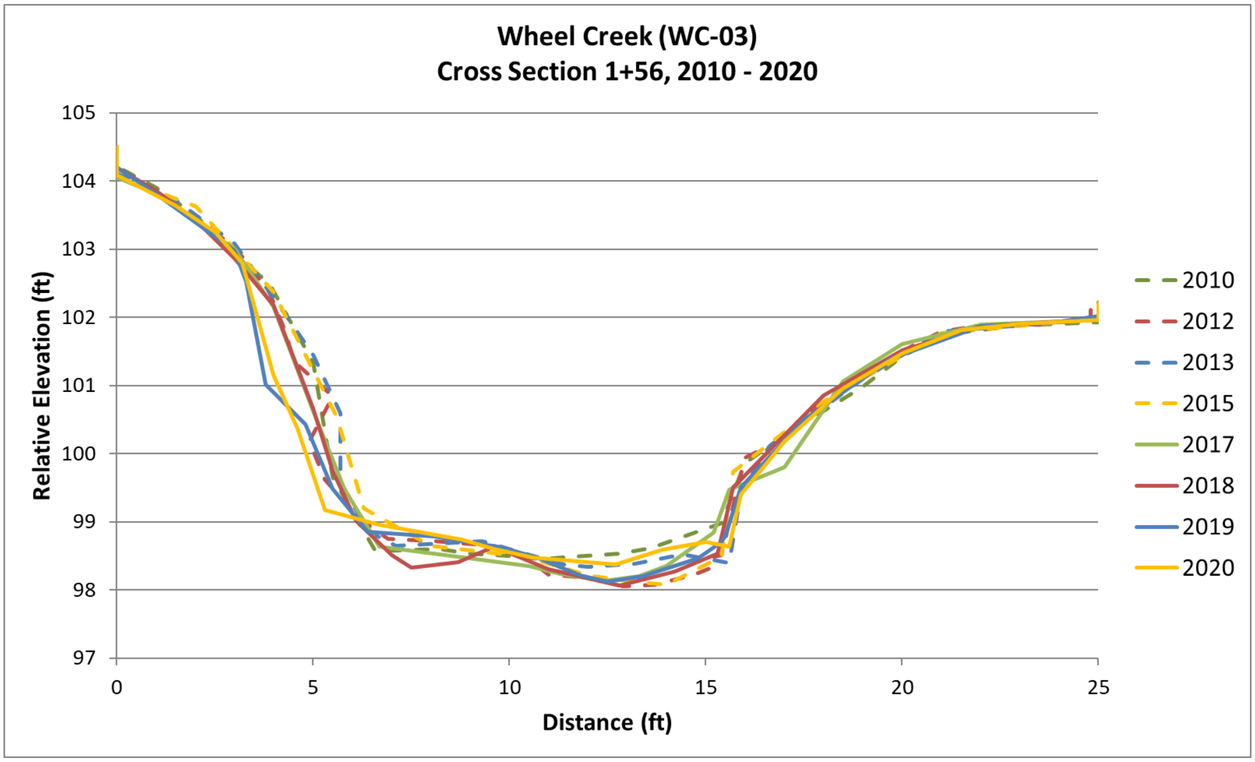

Figure C-15. WC03 Cross-section 1 (Pre- and Post-Restoration)

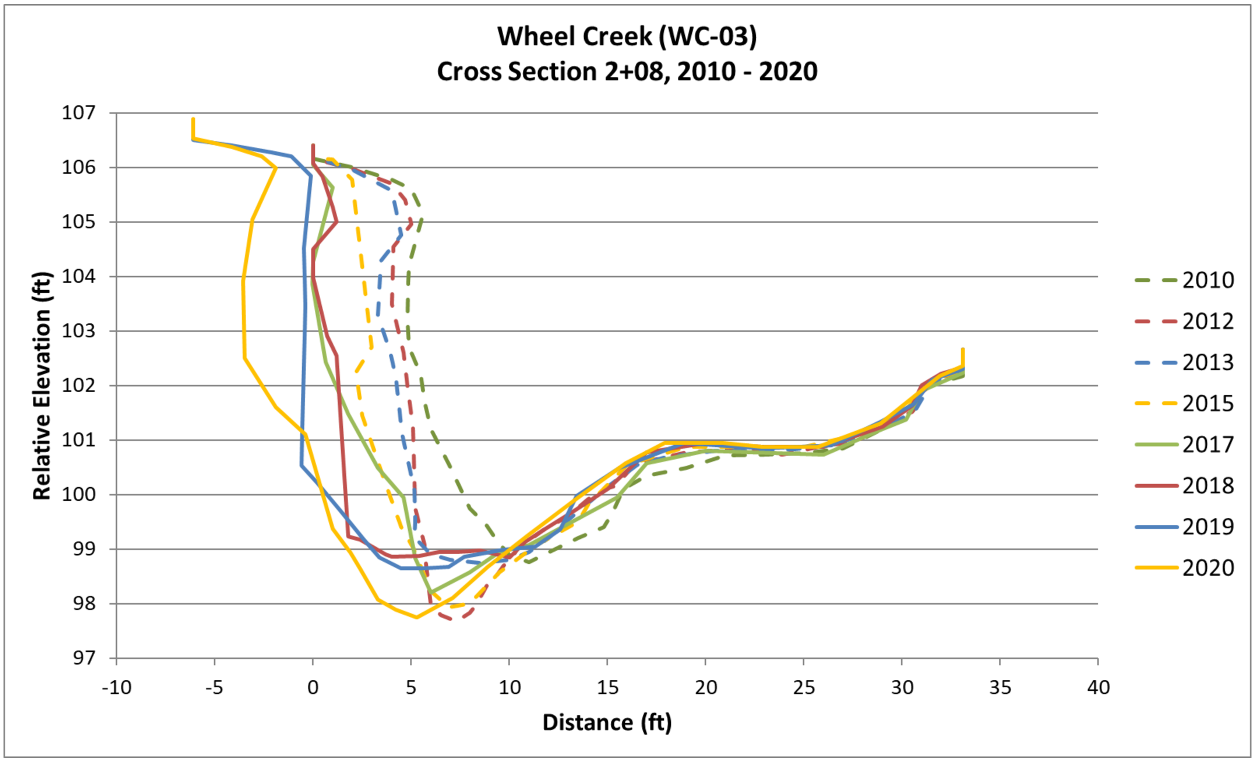

Figure C-16. WC03 Cross-section 2 (Pre- and Post-Restoration)

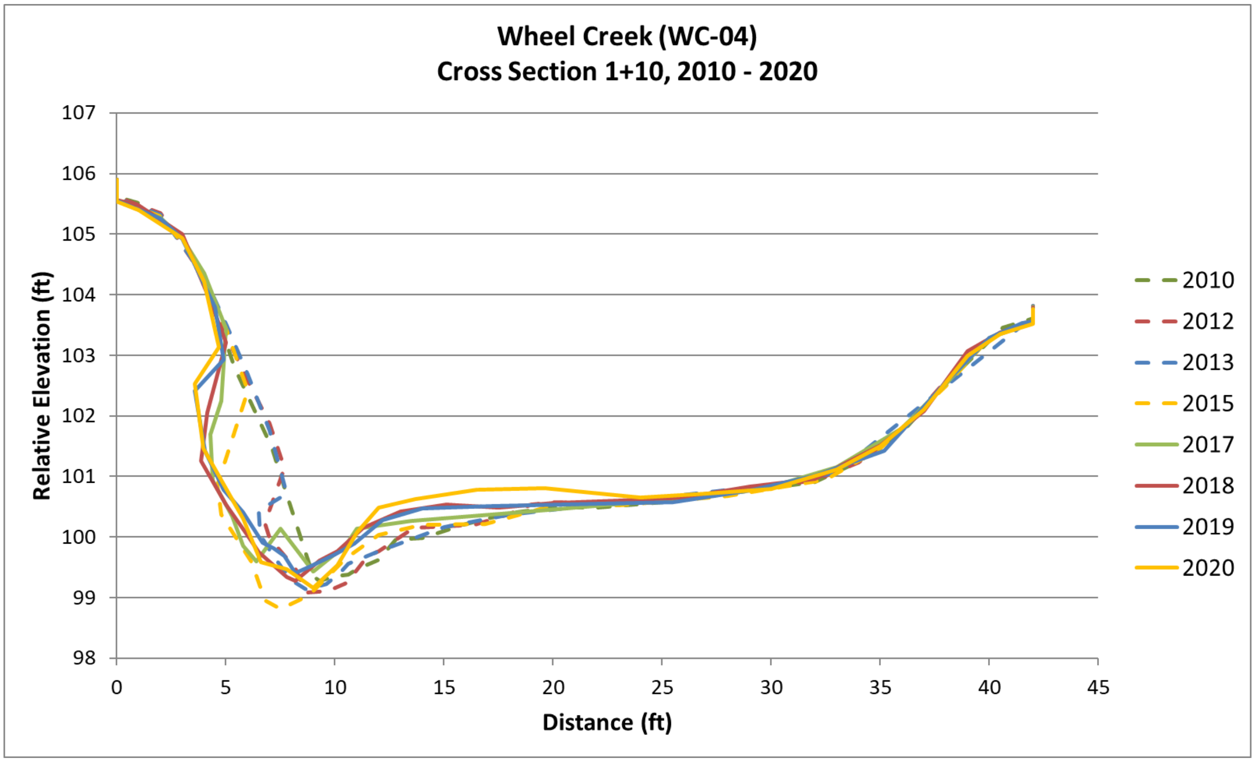

Figure C-17. WC04 Cross-section 1 (Pre- and Post-Restoration)

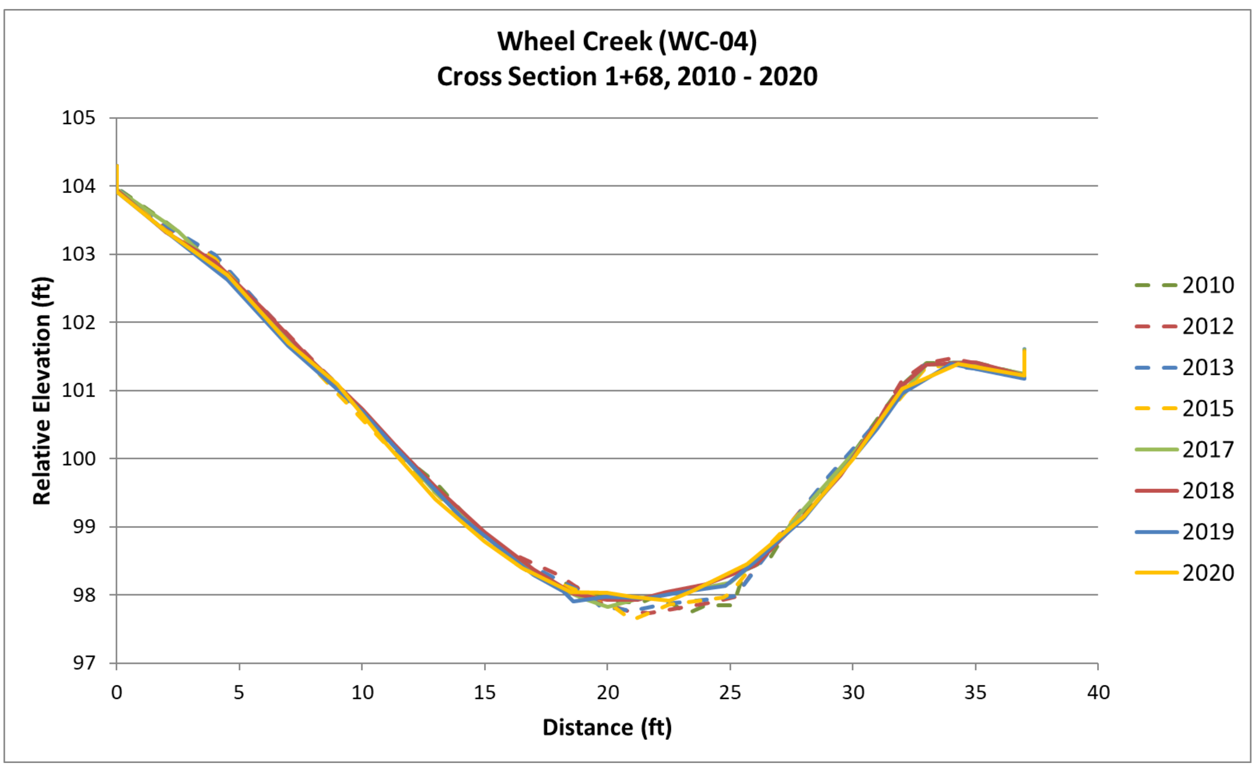

Figure C-18. WC04 Cross-section 2 (Pre- and Post-Restoration)

Table C-3. Particle Size Distribution Pre-Restoration Years 1 – 4, Post-Restoration Years 1 – 4

Year	***Riffle Feature Surface***			***Meander Feature Surface***			***Reachwide***		
	Measure	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
				WC01*					
2010	D50	39	very coarse gravel	D50	38	very coarse gravel	D50	44	very coarse gravel
2012	D50	56	very coarse gravel	D50	40	very coarse gravel	D50	51	very coarse gravel
2013	D50	49	very coarse gravel	D50	37	very coarse gravel	D50	55	very coarse gravel
2015	D50	50	very coarse gravel	D50	55	very coarse gravel	D50	42	very coarse gravel
2017	*D50*	*52*	*very coarse gravel*	*D50*	*11*	*medium gravel*	*D50*	*25*	*coarse gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*32*	*very coarse gravel*	*D50*	*47*	*very coarse gravel*
2019	*D50*	*47*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*37*	*very coarse gravel*
2020	*D50*	*42*	*very coarse gravel*	*D50*	*25*	*coarse gravel*	*D50*	*32*	*coarse gravel*
2010	D84	120	medium cobble	D84	90	medium cobble	D84	140	large cobble
2012	D84	180	large cobble	D84	77	small cobble	D84	120	medium cobble
2013	D84	130	large cobble	D84	87	small cobble	D84	130	large cobble
2015	D84	160	large cobble	D84	110	medium cobble	D84	150	large cobble
2017	*D84*	*120*	*small cobble*	*D84*	*57*	*very coarse gravel*	*D84*	*90*	*small cobble*
2018	*D84*	*150*	*large cobble*	*D84*	*97*	*medium cobble*	*D84*	*160*	*large cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*51*	*very coarse gravel*	*D84*	*90*	*small cobble*
2020	*D84*	*110*	*medium cobble*	*D84*	*84*	*small cobble*	*D84*	*93*	*medium cobble*
				WC02*					
2010	D50	50	very coarse gravel	D50	45	very coarse gravel	D50	49	very coarse gravel
2012	D50	40	very coarse gravel	D50	33	very coarse gravel	D50	28	coarse gravel
2013	D50	51	very coarse gravel	D50	47	very coarse gravel	D50	40	coarse gravel
2015	D50	36	very coarse gravel	D50	26	very coarse gravel	D50	36	very coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*4.3*	*very fine gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*64*	*small cobble*	*D50*	*27*	*coarse gravel*
2019	*D50*	*51*	*very coarse gravel*	*D50*	*16*	*medium gravel*	*D50*	*22*	*coarse gravel*
2020	*D50*	*82*	*small cobble*	*D50*	*43*	*very coarse gravel*	*D50*	*37*	*very coarse gravel*
2010	D84	98	medium cobble	D84	94	medium cobble	D84	100	medium cobble
2012	D84	80	small cobble	D84	69	small cobble	D84	80	small cobble
2013	D84	88	small cobble	D84	86	small cobble	D84	110	medium cobble
2015	D84	100	medium cobble	D84	100	medium cobble	D84	110	medium cobble
2017	*D84*	*85*	*very coarse gravel*	*D84*	*19*	*medium gravel*	*D84*	*62*	*very coarse gravel*
2018	*D84*	*120*	*medium cobble*	*D84*	*130*	*large cobble*	*D84*	*110*	*medium cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*64*	*small cobble*	*D84*	*76*	*small cobble*
2020	*D84*	*150*	*large cobble*	*D84*	*100*	*medium cobble*	*D84*	*80*	*small cobble*
				WC03					
2010	D50	33	very coarse gravel	D50	8.7	medium gravel	D50	28	coarse gravel
2012	D50	27	coarse gravel	D50	15	medium gravel	D50	23	coarse gravel
2013	D50	27	coarse gravel	D50	29	coarse gravel	D50	35	very coarse gravel
2015	D50	36	very coarse gravel	D50	7.2	fine gravel	D50	26	coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*17*	*medium gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*26*	*coarse gravel*	*D50*	*14*	*medium gravel*	*D50*	*22*	*coarse gravel*
2019	*D50*	*45*	*very coarse gravel*	*D50*	*23*	*coarse gravel*	*D50*	*22*	*coarse gravel*
2020	*D50*	*36*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*31*	*coarse gravel*
2010	D84	74	small cobble	D84	72	small cobble	D84	75	small cobble
2012	D84	59	very coarse gravel	D84	43	very coarse gravel	D84	72	small cobble
2013	D84	68	small cobble	D84	59	very coarse gravel	D84	130	large cobble
2015	D84	85	small cobble	D84	30	coarse gravel	D84	69	small cobble
2017	*D84*	*59*	*very coarse gravel*	*D84*	*61*	*very coarse gravel*	*D84*	*50*	*very coarse gravel*
2018	*D84*	*69*	*small cobble*	*D84*	*50*	*very coarse gravel*	*D84*	*51*	*very coarse gravel*
2019	*D84*	*88*	*small cobble*	*D84*	*70*	*small cobble*	*D84*	*80*	*small cobble*
2020	*D84*	*77*	*small cobble*	*D84*	*44*	*very coarse gravel*	*D84*	*71*	*small cobble*
				WC04					
2010	D50	30	coarse gravel	D50	18	coarse gravel	D50	22	coarse gravel
2012	D50	36	very coarse gravel	D50	15	medium gravel	D50	24	coarse gravel
2013	D50	33	very coarse gravel	D50	1.5	very coarse sand	D50	36	very coarse gravel

Table C-3. Continued									
	Riffle Feature Surface			***Meander Feature Surface***			***Reachwide***		
Year	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
WC04									
2015	D50	35	very coarse gravel	D50	8.3	medium gravel	D50	28	coarse gravel
2017	*D50*	*43*	*coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*21*	*medium gravel*
2018	*D50*	*33*	*very coarse gravel*	*D50*	*1.9*	*very coarse sand*	*D50*	*17*	*coarse gravel*
2019	*D50*	*27*	*coarse gravel*	*D50*	*1.2*	*very coarse sand*	*D50*	*23*	*coarse gravel*
2020	*D50*	*49*	*very coarse gravel*	*D50*	*20*	*coarse sand*	*D50*	*22*	*coarse gravel*
2010	D84	80	small cobble	D84	87	small cobble	D84	71	small cobble
2012	D84	64	small cobble	D84	70	small cobble	D84	76	small cobble
2013	D84	57	very coarse gravel	D84	64	small cobble	D84	79	small cobble
2015	D84	66	small cobble	D84	24	coarse gravel	D84	72	small cobble
2017	*D84*	*99*	*small cobble*	*D84*	*26*	*coarse gravel*	*D84*	*68*	*very coarse gravel*
2018	*D84*	*70*	*small cobble*	*D84*	*32*	*very coarse gravel*	*D84*	*47*	*very coarse gravel*
2019	*D84*	*80*	*small cobble*	*D84*	*29*	*coarse gravel*	*D84*	*81*	*small cobble*
2020	*D84*	*92*	*medium cobble*	*D84*	*58*	*very coarse gravel*	*D84*	*75*	*small cobble*
*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)									

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